*NOAA Technical Memorandum NMFS-F/NEC-73

Surface and Bottom Temperature Distribution for the Northeast Continental Shelf

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northeast Fisheries Center
Woods Hole, Massachusetts

December 1989

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Surface and Bottom Temperature Distribution for the Northeast Continental Shelf

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Abstract

Horizontal distributions of expected or mean surface and bottom temperatures on the Northeast Continental Shelf from Cape Hatteras to the Gulf of Maine are presented for the beginning and middle of each month. Data used to generate these distributions are from the period 1977-87. The distributions, therefore, represent an 11-year mean annual temperature cycle. Horizontal distributions of the interannual variability in temperature within the 11-year period are also presented.

Introduction

At mid-latitudes, continental shelf waters exhibit a large seasonal change in temperature, warming in the spring and summer and cooling in the fall and winter. This annual cycle of temperature exerts a strong influence on the distribution and migratory habits of many fish species. It also influences the time of spawning for some species and may affect feeding and growth rate directly.

This report presents horizontal distributions of the expected or mean surface and bottom temperature on the Northeast Continental Shelf of the United States from Cape Hatteras to the Gulf of Maine for the beginning and middle of each month. The data used to generate these distributions are from the period 1977-87 and were obtained as part of the Marine Resources Monitoring, Assessment, and Prediction (MARMAP) program. MARMAP is an interdisciplinary program to measure the distribution of plankton, nutrients, and physical water properties over the continental shelf from Cape Hatteras to the Gulf of Maine (Sherman 1980). Summaries of other parameters measured by MARMAP may be found in Morse et al. (1987) and Sibunka and Silverman (1984).

The extreme temperatures in the water column are found generally at the surface and the bottom. The distributions presented, therefore, indicate the range of temperatures that likely would be encountered in the water column. The only consistent exception is in the Gulf of Maine during the spring and summer. There the coldest temperatures occur in an intermediate layer (50-125 m depth) and represent a remnant of the previous winter's cooling (Hopkins and Garfield 1979).

The MARMAP sampling included observations of salinity. The interannual variability in salinity. of the shelf waters was found however, to be as large or larger than the seasonal changes of salinity. Therefore, no characteristic annual cycle of salinity could be determined comparable to the temperature cycle presented in this report.

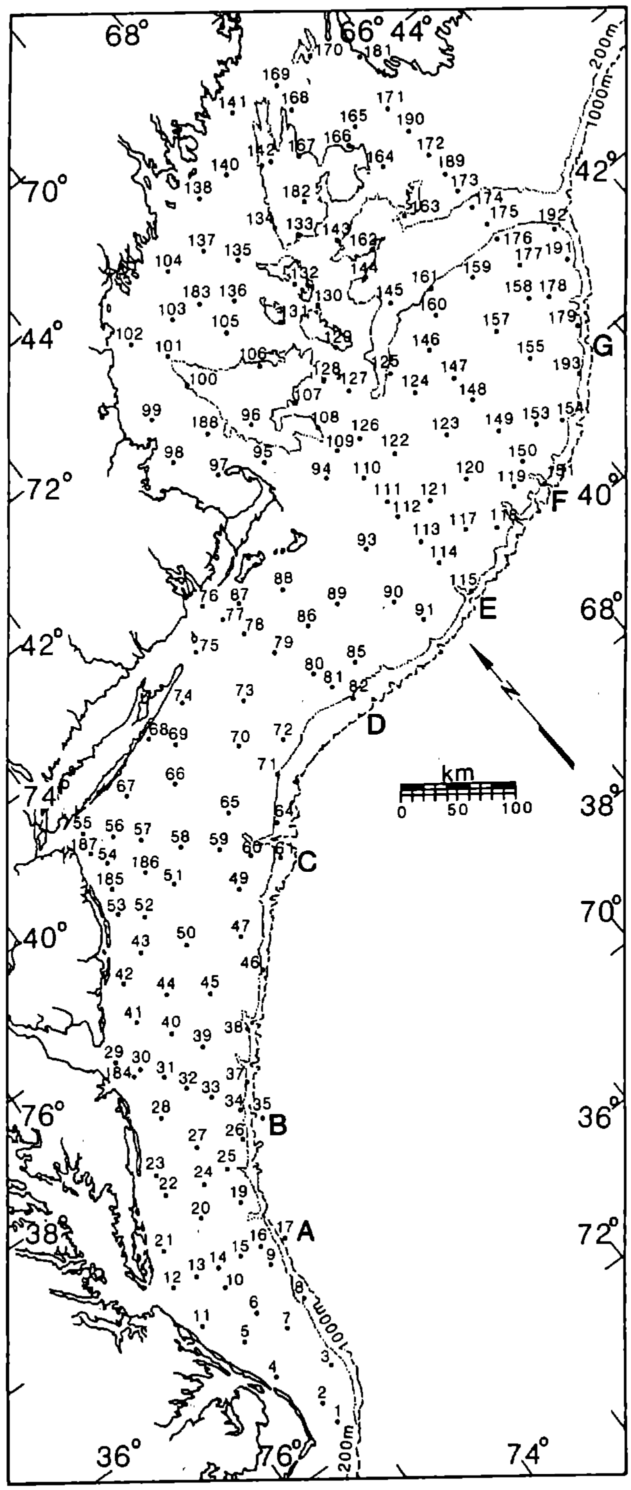

Figure 1. Location of MARMAP standard stations.

The Data

The MARMAP program made observations three to six times per year at over 180 standard station. locations (Figure 1). The standard stations are separated by about 30 km; not all stations were occupied on each cruise. During 1977-87, hydrographic measurements were made on 49 MARMAP survey cruises.

Water properties were measured generally using water bottles and reversing thermometers at up to 15 standard depths, although in 1987 a conductivity, temperature, and pressure profiling instrument (i.e., CTD) was used on some cruises. The accuracy of the temperature data is approximately 0.02ºC. For this report only, the surface and near-bottom temperature observations from the MARMAP data set were used. An observation had to be within 5 m of the surface to be considered a surface value and within 10 m of the bottom to be used as a bottom value.

Determining the Annual Temperature Cycle

The MARMAP data set supplies repeated observations of water properties at essentially fixed locations. The repeated sampling permits an analytical description of the annual cycle of surface and bottom temperature at a location. To do this, all of the observations at a MARMAP station were combined, regardless of year, with the dates expressed only as Julian day. If there were at least 10 observations for a station and at least one in each quarter of the year, an annual curve was calculated.

The annual curve fit to the data is the sum of three sinusoidal components which have frequencies of one, two, or three cycles per year. To fit the different harmonic components, a multiple regression model was used with the form:

$$T = \sum_{j=1,3} [M_j + A_j \cdot \cos(2\pi \cdot JD / P_j) + B_j \cdot \sin(2\pi \cdot JD / P_j)]$$

where:

T = temperature;
M_j = the mean temperature for the j^{th} component;
JD = Julian day;
A_j = cosine amplitude for the j^{th} component;
B_j = sine amplitude for the j^{th} component; and
P_j = the harmonic period for the j^{th} component.

The independent variables are the cosine and sine terms, evaluated for the Julian day of each observation and the harmonic period being considered. The model then has the form:

$$T = M + A * X_1 + B * X_2$$

where X_1 is the cosine variable and X_2 is the sine variable. The values of A and B were determined as follows (SPSS Inc. 1975):

$$A = \frac{SP[T,1] \cdot SS[2] - SP[T,2] \cdot SP[1,2]}{SS[1] \cdot SS[2] - SP[1,2] \cdot SP[1,2]}$$

$$B = \frac{SP[T,2] \cdot SS[1] - SP[T,1] \cdot SP[1,2]}{SS[1] \cdot SS[2] - SP[1,2] \cdot SP[1,2]}$$

$$M = T - A \cdot \bar{X}_1 - B \cdot \bar{X}_2$$

where SS stand for sum of squares and SP stands for sum of products:

$$SS[1] = \Sigma (X_{1i} - \bar{X}_1)^2 = \Sigma X_{1i}^2 - (\Sigma X_{1i})(\Sigma X_{1i}) / N$$

$$SP[1,2] = \Sigma (X_{1i} - \bar{X}_1)(X_{2i} - \bar{X}_2) = \Sigma(X_{2i} \cdot X_{2i}) - (\Sigma X_{1i})(\Sigma X_{2i}) / N$$

where N is the number of points and the summations are from i = 1 to N.

The curve-fitting procedure first fits an annual harmonic (P = 365 days) to the original data set. The mean, cosine, and sine coefficients are determined by the above expressions. The significance of the regression coefficients is tested as described by Fofonoff and Bryden (1975) and Brownlee (1965). If the annual curve is significant at the 95 percent level, it is accepted and the residuals (i.e., the differences between the original data and the calculated annual curve) are the input data for fitting the second harmonic with a period of 365/2 days. The significance of this curve is tested. If accepted, the residuals are again determined and a third harmonic with P = 365/3 is fit to them. The second and third harmonics will have small mean values associated with them. The mean value for the year is the sum of the three means.

The inclusion of a fourth harmonic (P = 365/4) does not provide any statistically significant improvement in the results, and, therefore, only the first three harmonics are considered.

The standard deviation of the original temperature data from the combined annual curve is determined. Any points that are more than two standard deviations from the calculated curve are identified., The curve-fitting process is repeated with these points omitted to prevent the rare occurrence of an external water mass (e.g., slope water or Gulf Stream water) from distorting the calculated annual cycle of the dominant, local water mass. The results of the second curve fitting are the values accepted and used.,

An example of the curve-fitting results is shown in Figure 2 for the bottom temperature at MARMAP station 56, located in the inner New York Bight. The solid line is the mean annual curve and the dashed lines represent plus and minus one standard deviation from the mean. The original data points are plotted and keyed by year. The calculated mean curve follows the observations quite closely. The standard deviation results more from real interannual variability in the data than from an inability of the curve-fitting method to represent the original data.

A program for personal computers that uses these calculated annual curves to estimate the temperature anywhere on the shelf on any day of the year is presented by Mountain (1989).

Temperature Distributions

Using the annual curves for the MARMAP stations, the shelfwide distribution of temperature can be determined

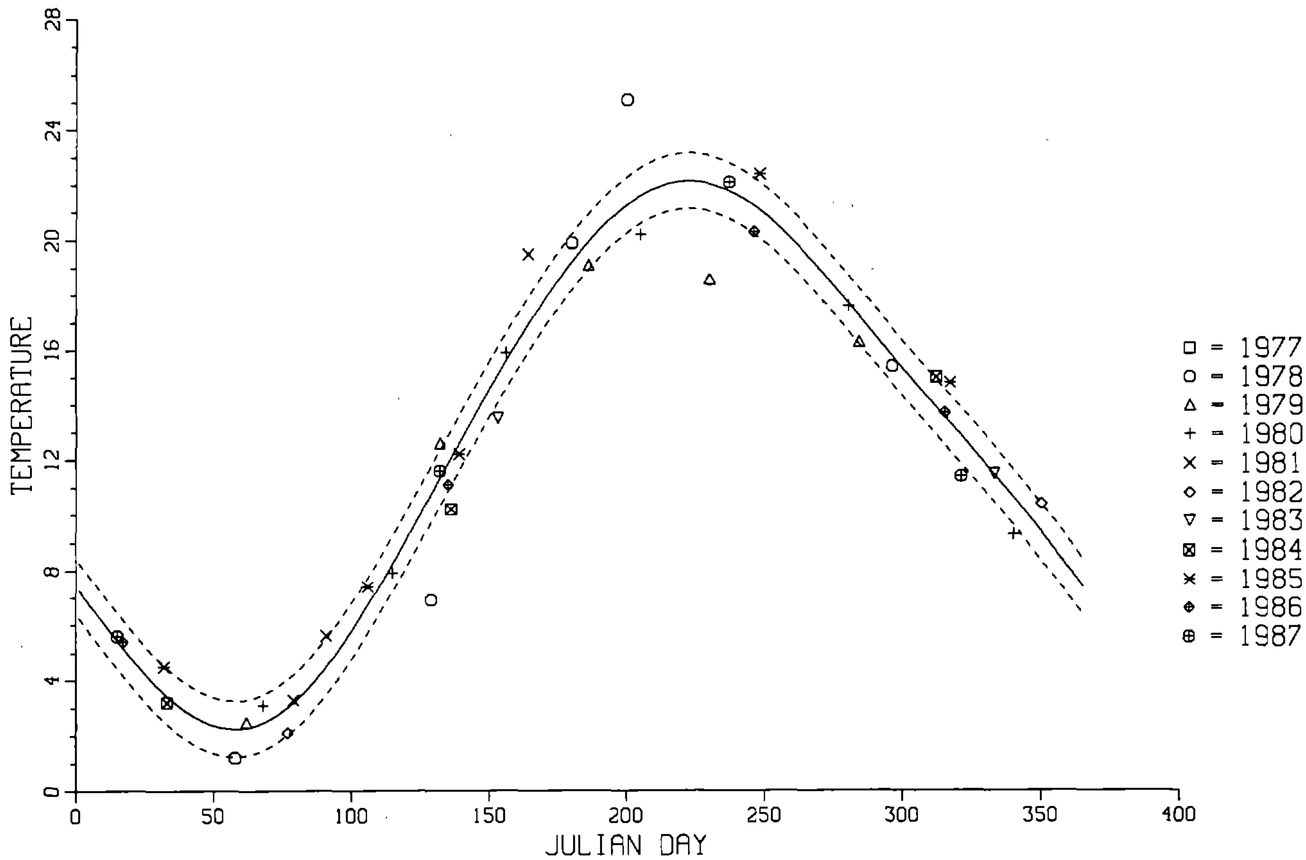

Figure 2. Calculated annual curve (solid line) for the bottom temperature at MARMAP station 56. The dashed curves represent plus and minus one standard deviation from the mean curve. The original data points are plotted with symbols indicating the year of the observation.

easily for any day of the year. The value for each station is calculated from its annual curve and then the values for all stations are plotted and contoured. The distributions for the expected surface and bottom temperature for the beginning and middle of each month are presented in Figures 3 through 26. The standard deviations of the surface and bottom annual temperature curves are presented in Figure 27 and are an indication of the interannual variability in temperature conditions. In most areas, this variability is between 0.5 and 1.5ºC.

The analytical form of the calculated annual curves allows other characteristics of the seasonal cycle of temperature on the shelf to be determined. The annual range of expected temperature is shown in Figure 28. The progression of the warming cycle along the shelf, indicated by the day of the year (Julian day) that the surface temperature first reaches 7ºC in the spring, is shown in Figure 29. An indication of the timing of seasonal cooling is shown by the first day the surface temperature falls below 12°C (Figure 30). The spring warming progresses along the shelf from south to north The fall and winter cooling, however, progresses primarily from the coast seaward across the shelf.

The data used to derive the temperature distributions presented were obtained over an 11-year period, 1977-87. In using these distributions, it is important to appreciate how the temperatures during these years compared to long-term climatic conditions. Figure 31 shows the annual average surface temperature at Boothbay Harbor, Maine, since 1906 (Churchill 1988). The average temperature for 1977-87 was 8.55ºC, which is close to the average for the whole record of 8.33ºC. The recent decade was intermediate between the high temperatures of the early 1950s and the cold conditions in the early 1940s and mid-1960s.

Acknowledgements

Numerous people worked many years to collect and process the temperature data used in this report and to them as a group the authors wish to express their gratitude. The 11-year time series of data would not have existed without the perseverance of Dr. Kenneth Sherman. James Manning wrote the computer programs that produced the contour figures in this report.

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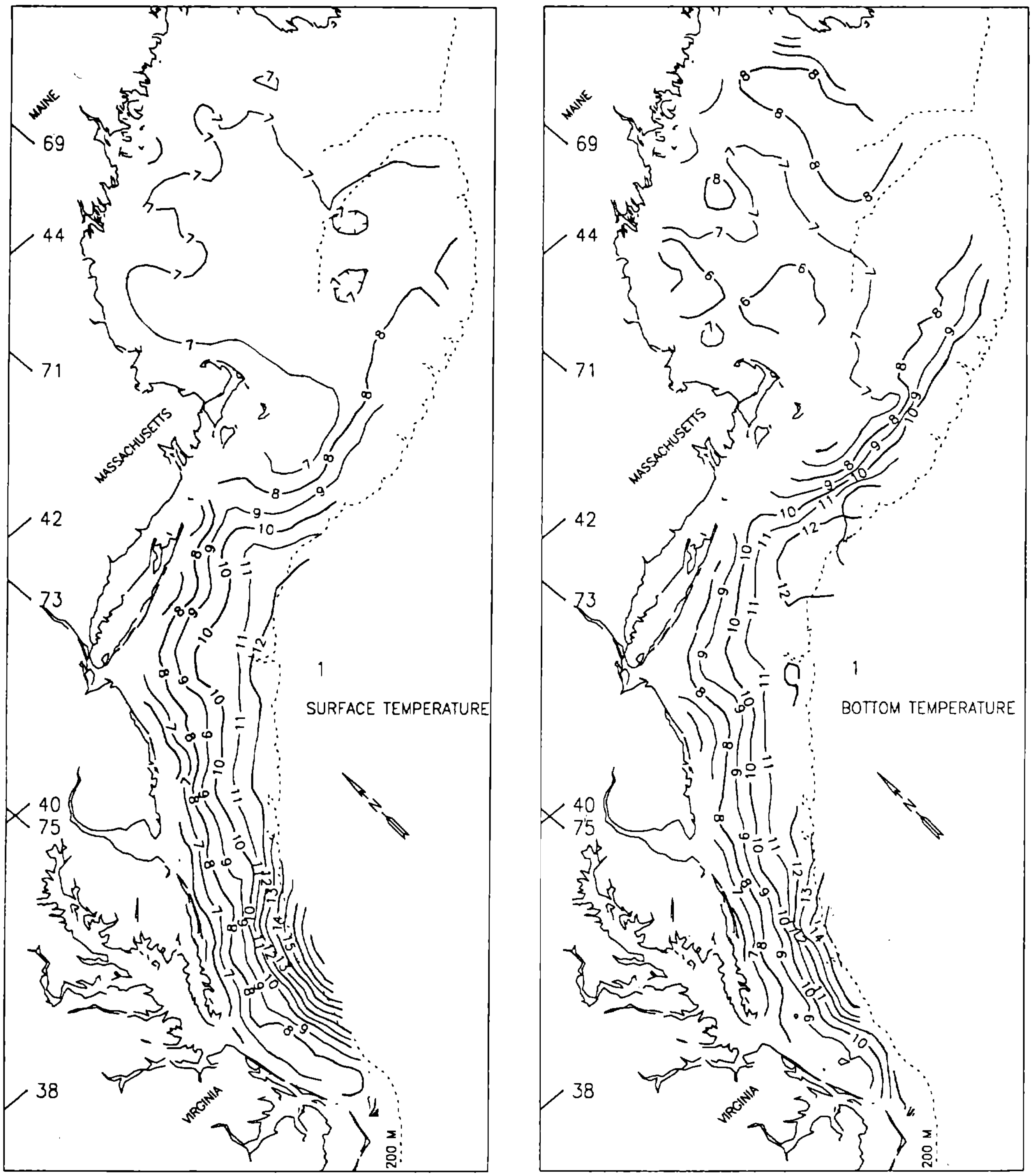


Figure 3. Expected (a) surface and (b) bottom temperature (°C) for January 1. The large numbers above the legend indicate the Julian day.

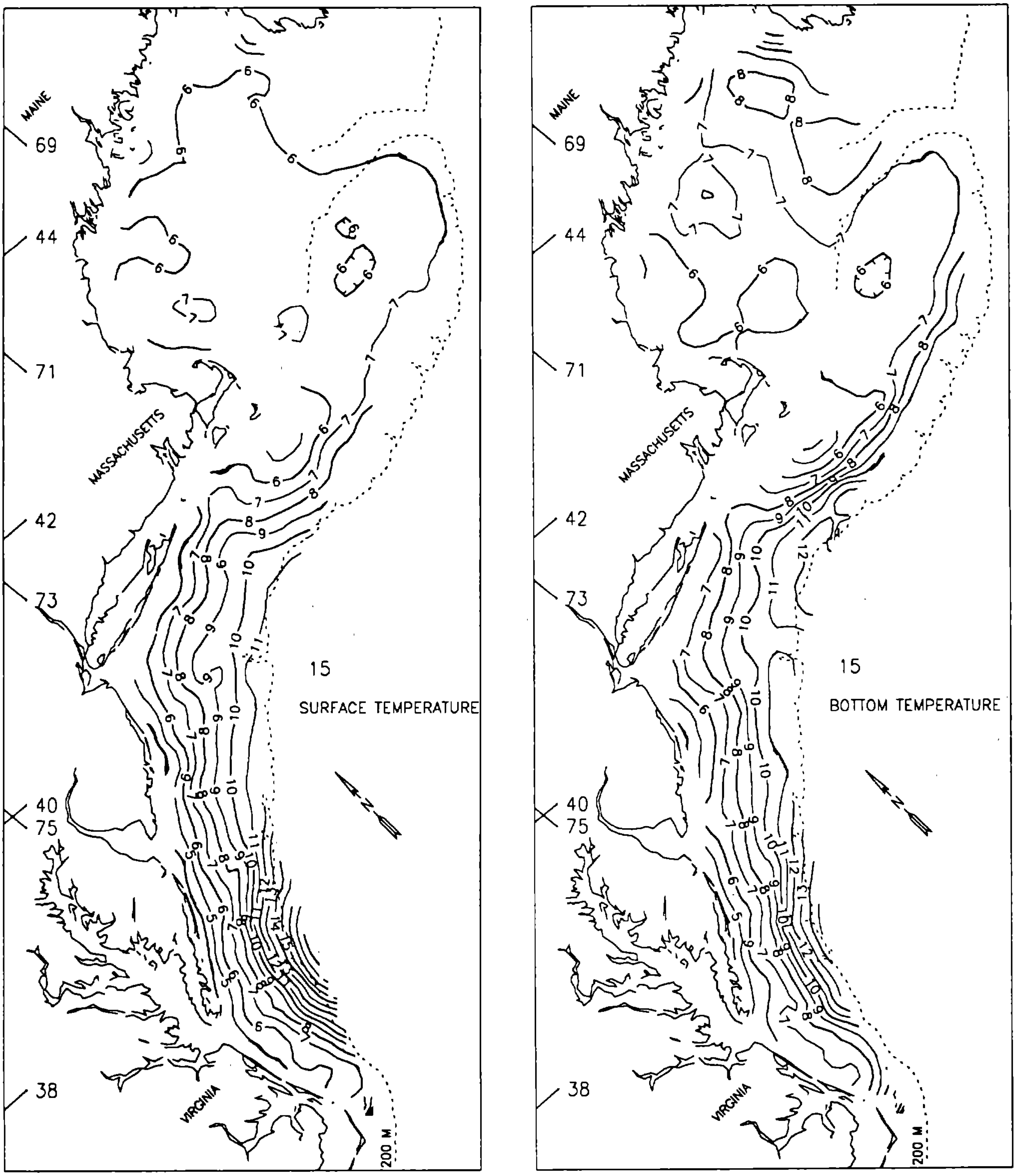


Figure 4. Expected (a) surface and (b) bottom temperature (‘C) for January 15. The large numbers above the legend indicate the Julian day.

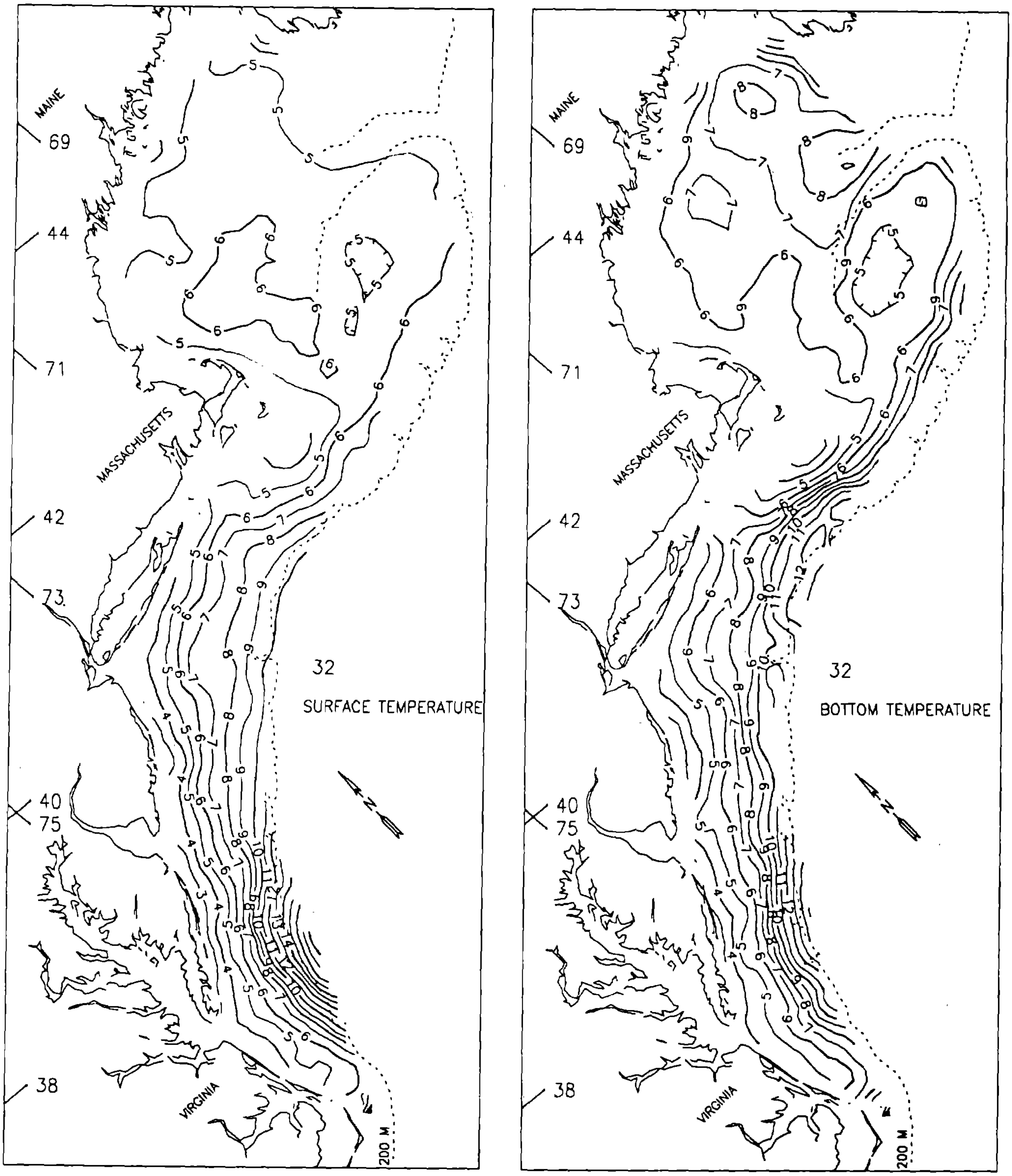


Figure 5. Expected (a) surface and (b) bottom temperature (“C) for February 1. The large numbers above the legend indicate the Julian day.

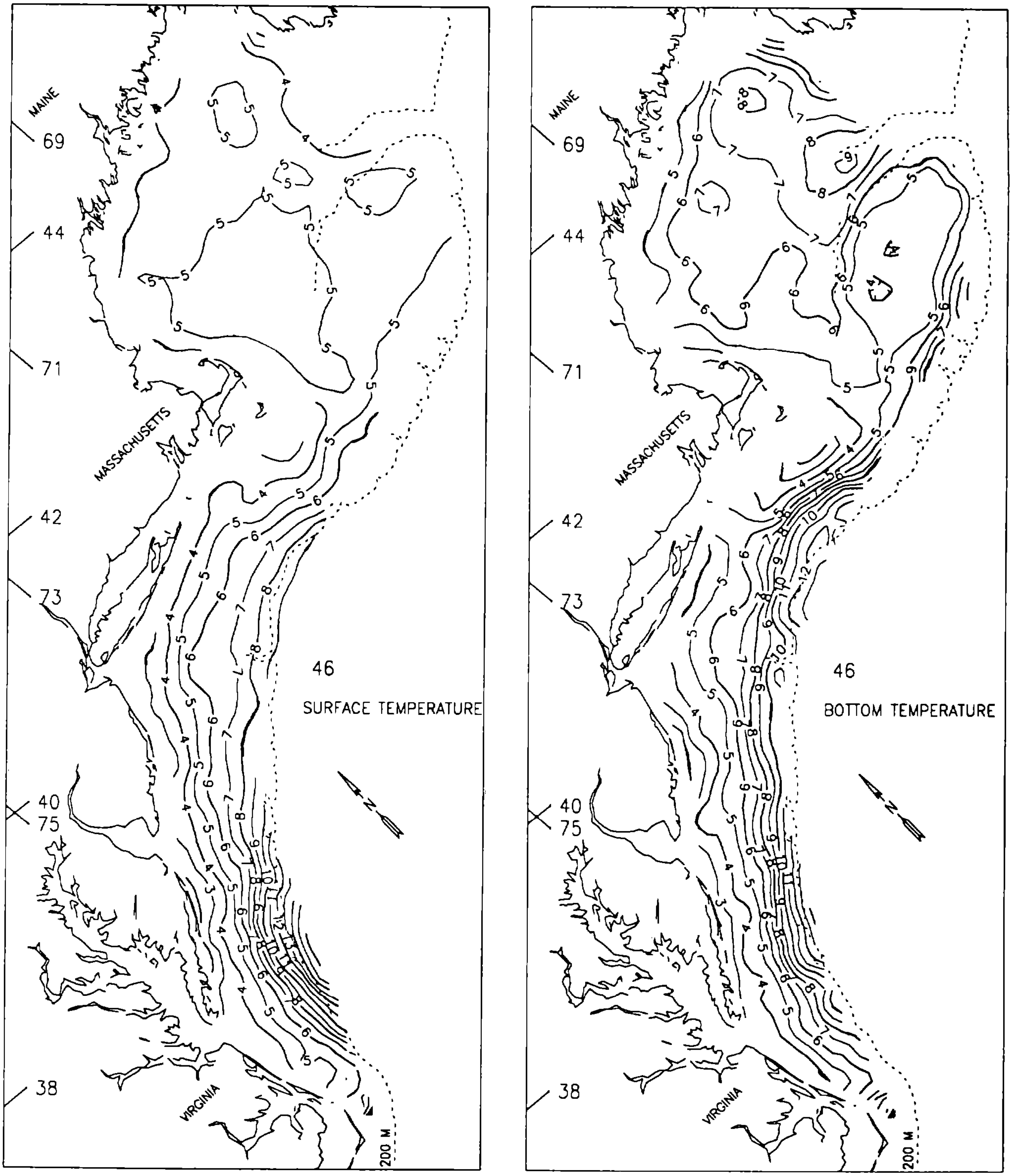
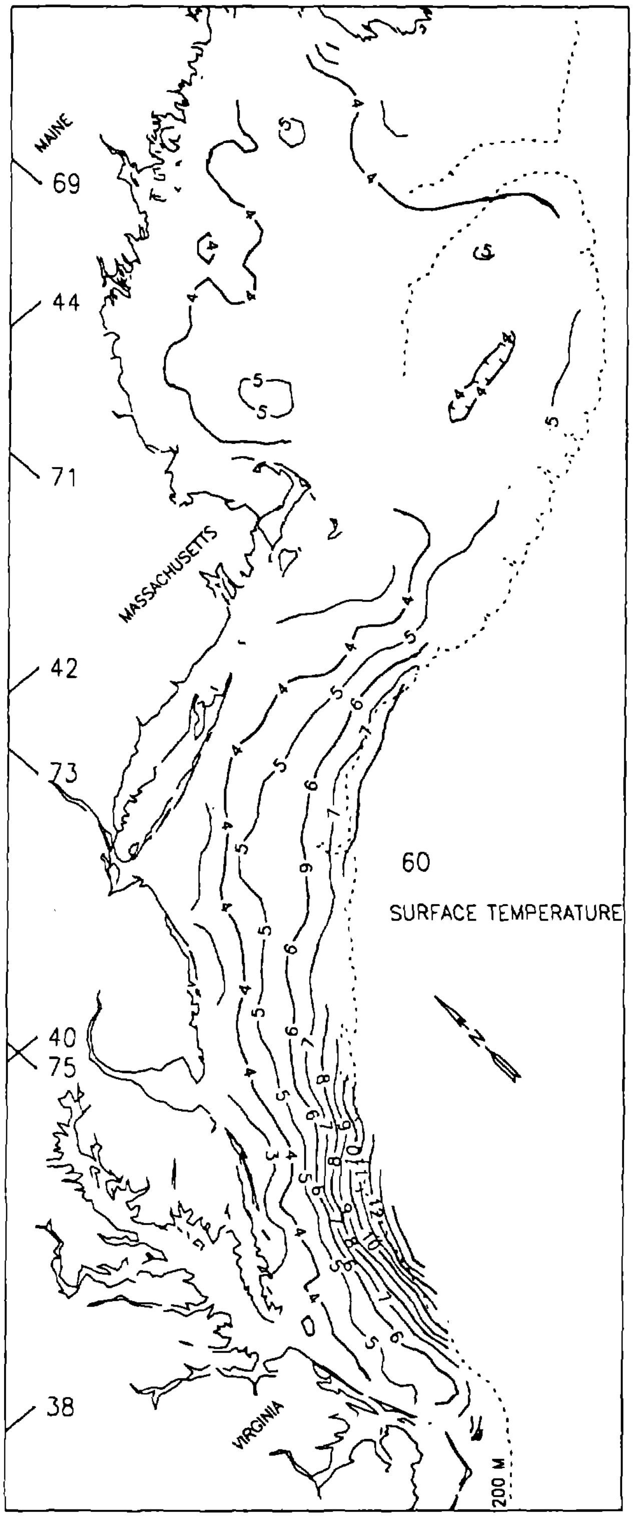


Figure 6. Expected (a) surface and (b) bottom temperature (“C) for February 1.5. The large numbers above the legend indicate the Julian day.



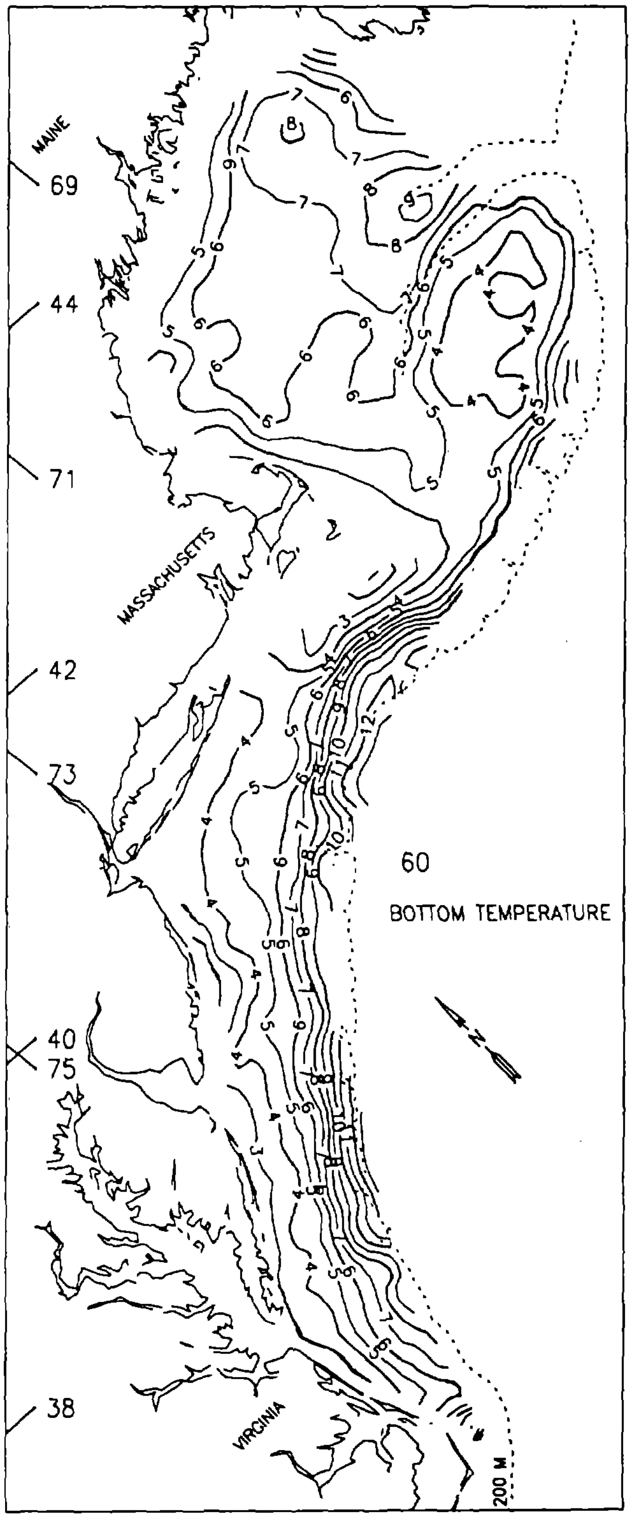
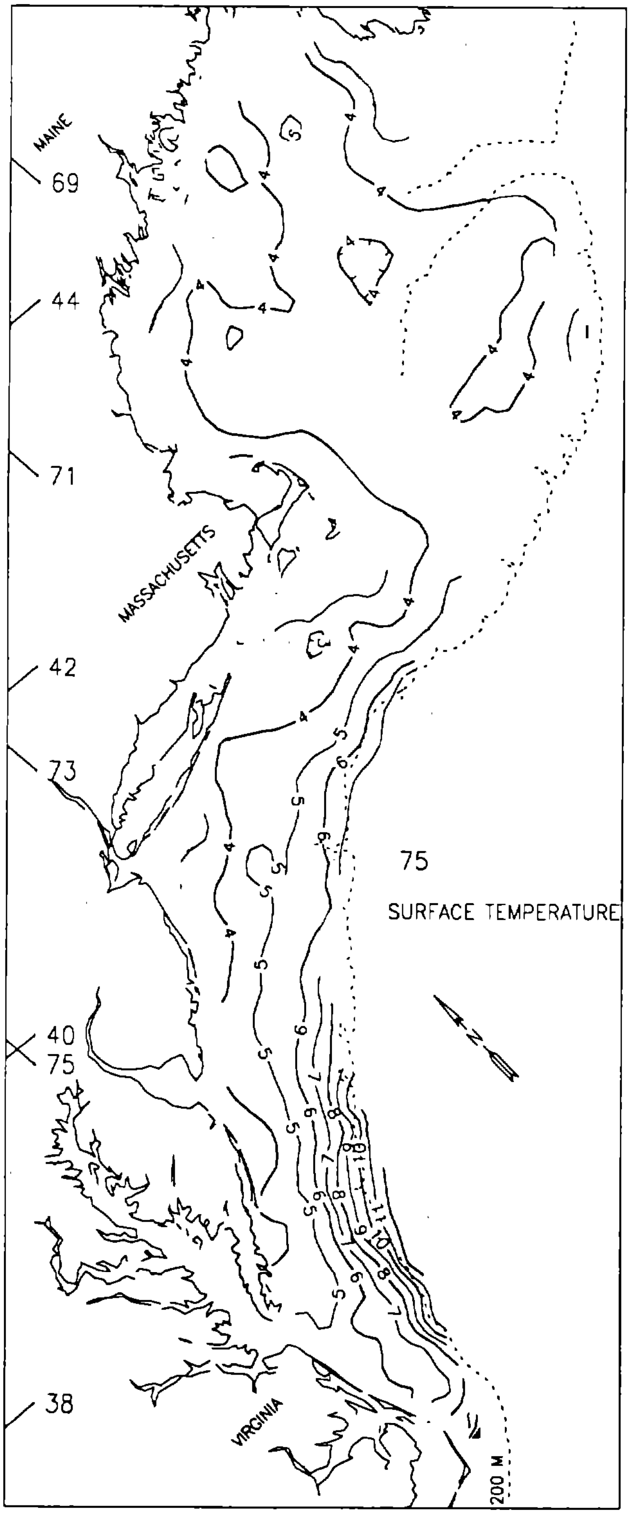


Figure 7. Expected (a) surface and (b) bottom temperature (“C) for March 1. The large numbers above the legend indicate the Julian day.



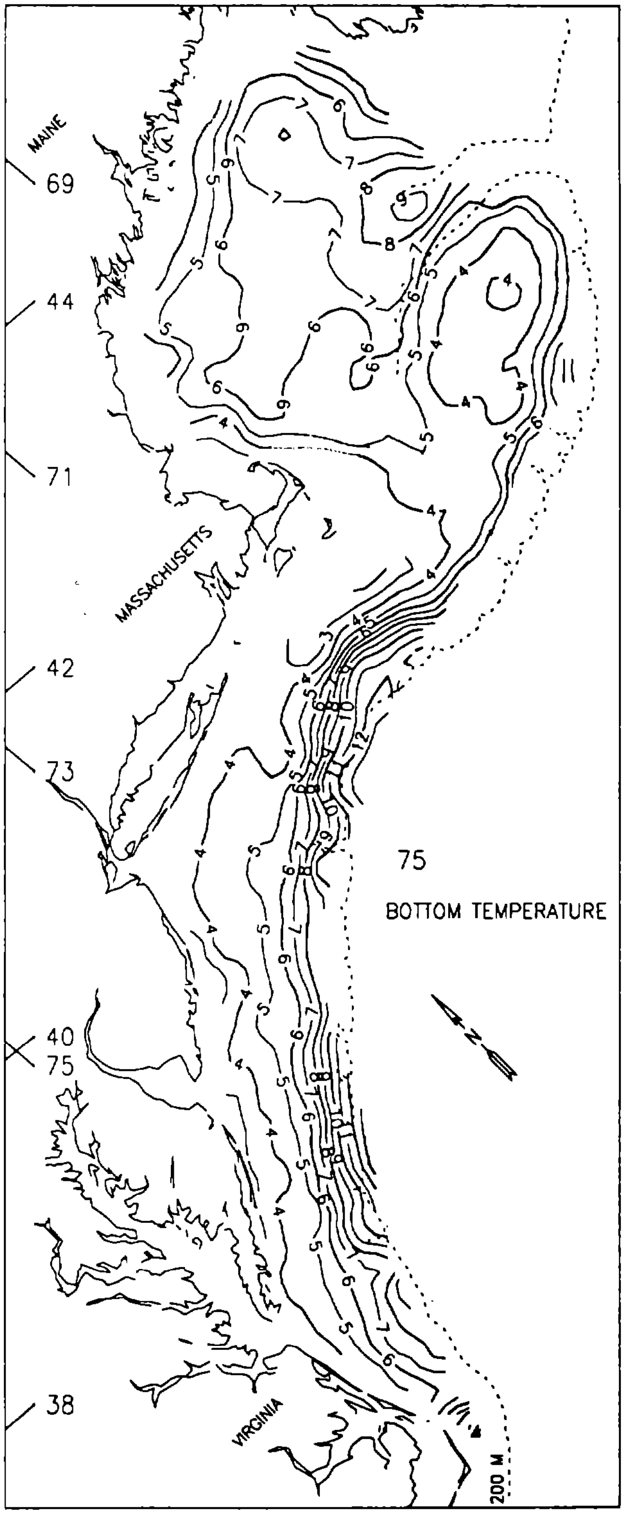


Figure 8. Expected (a) surface and (b) bottom temperature (‘C) for March 15. The large numbers above the legend indicate the Julian day.

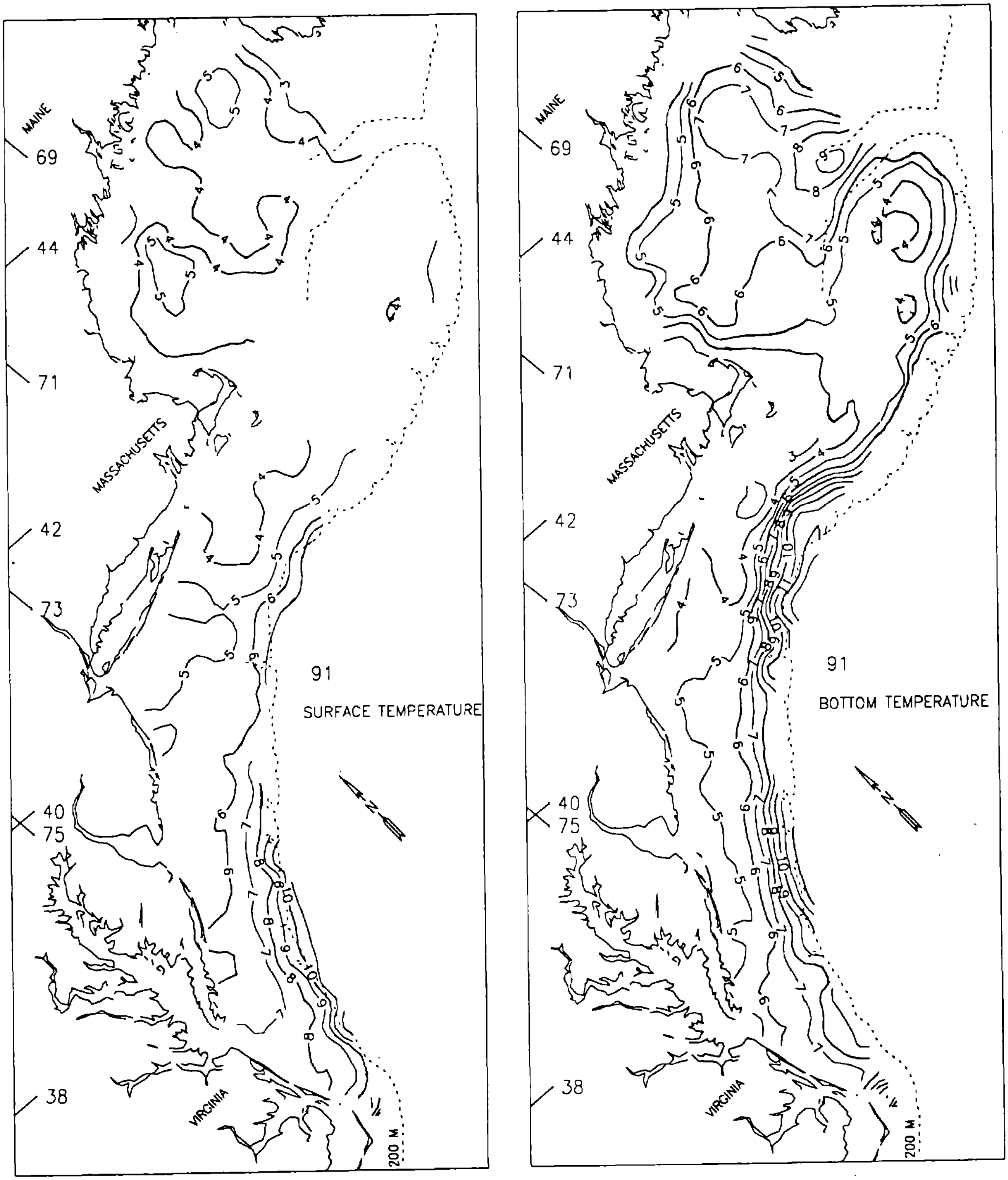


Figure 9. Expected (a) surface and (b) bottom temperature (ºC) for April 1. The large numbers above the legend indicate the Julian day.

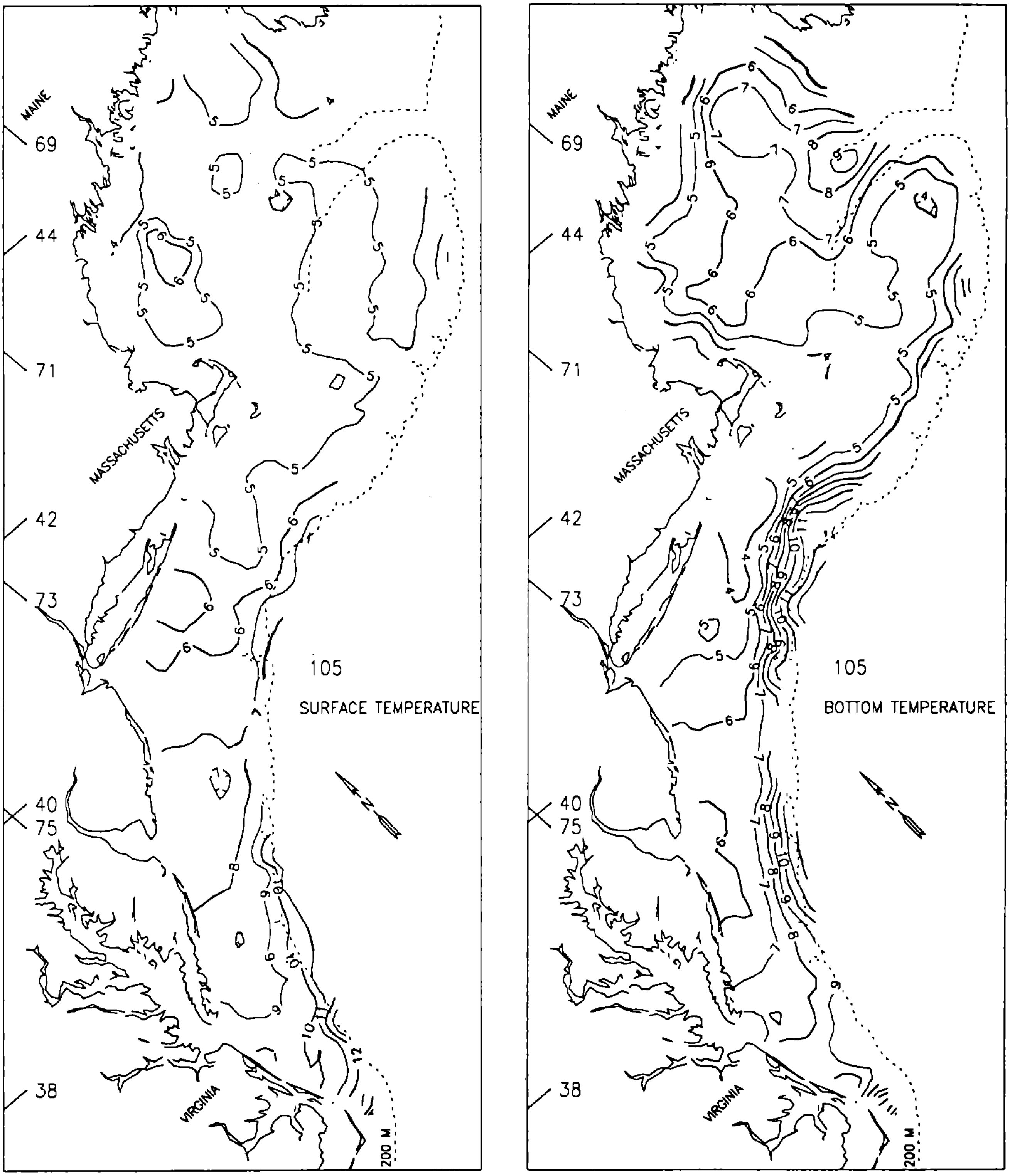


Figure 10. Expected (a) surface and (b) bottom temperature (‘C) for April 15. The large numbers above the legend indicate the Julian day.

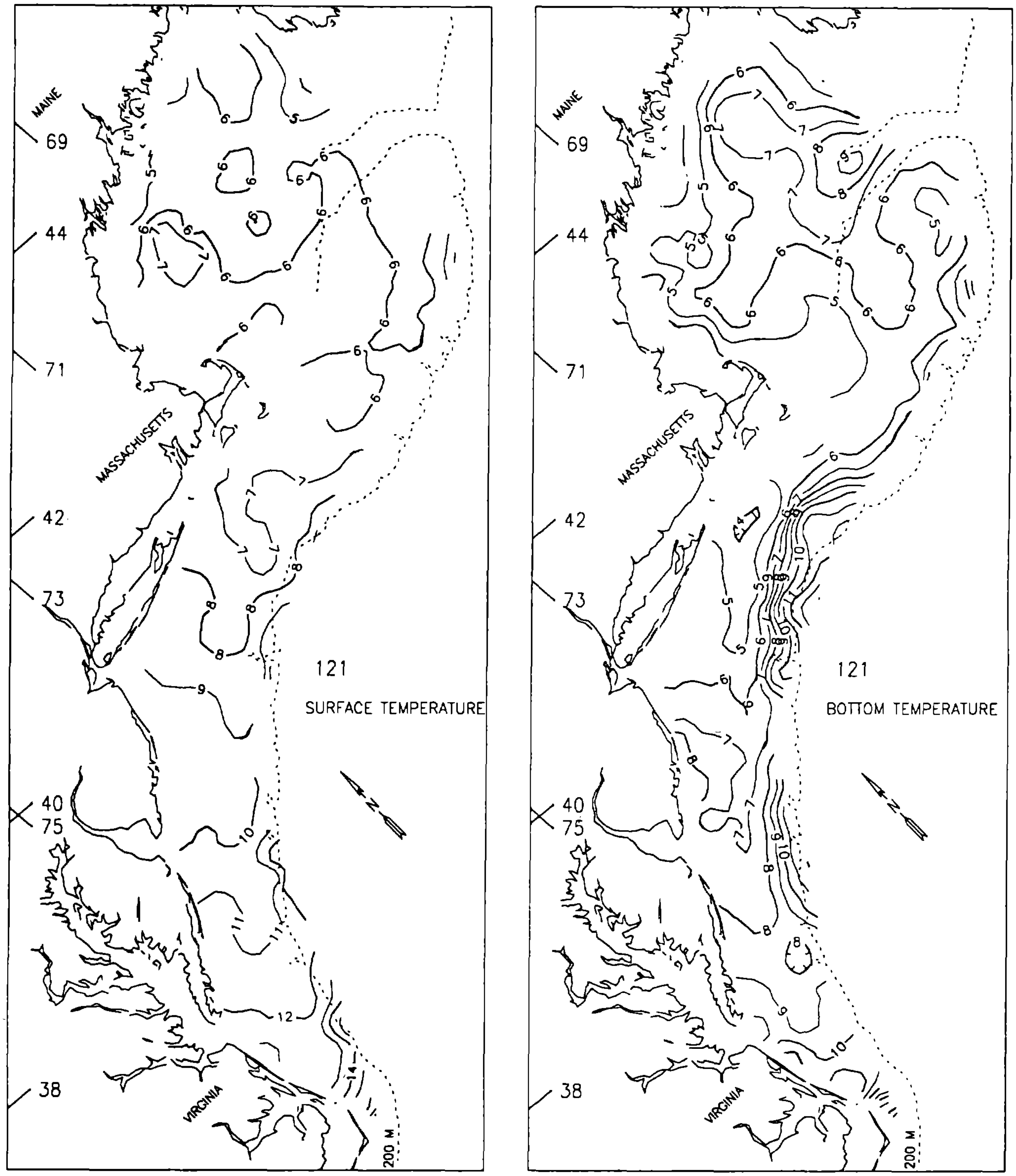


Figure 11. Expected (a) surface and (b) bottom temperature (ºC) for May 1. The large numbers above the legend indicate the Julian day.

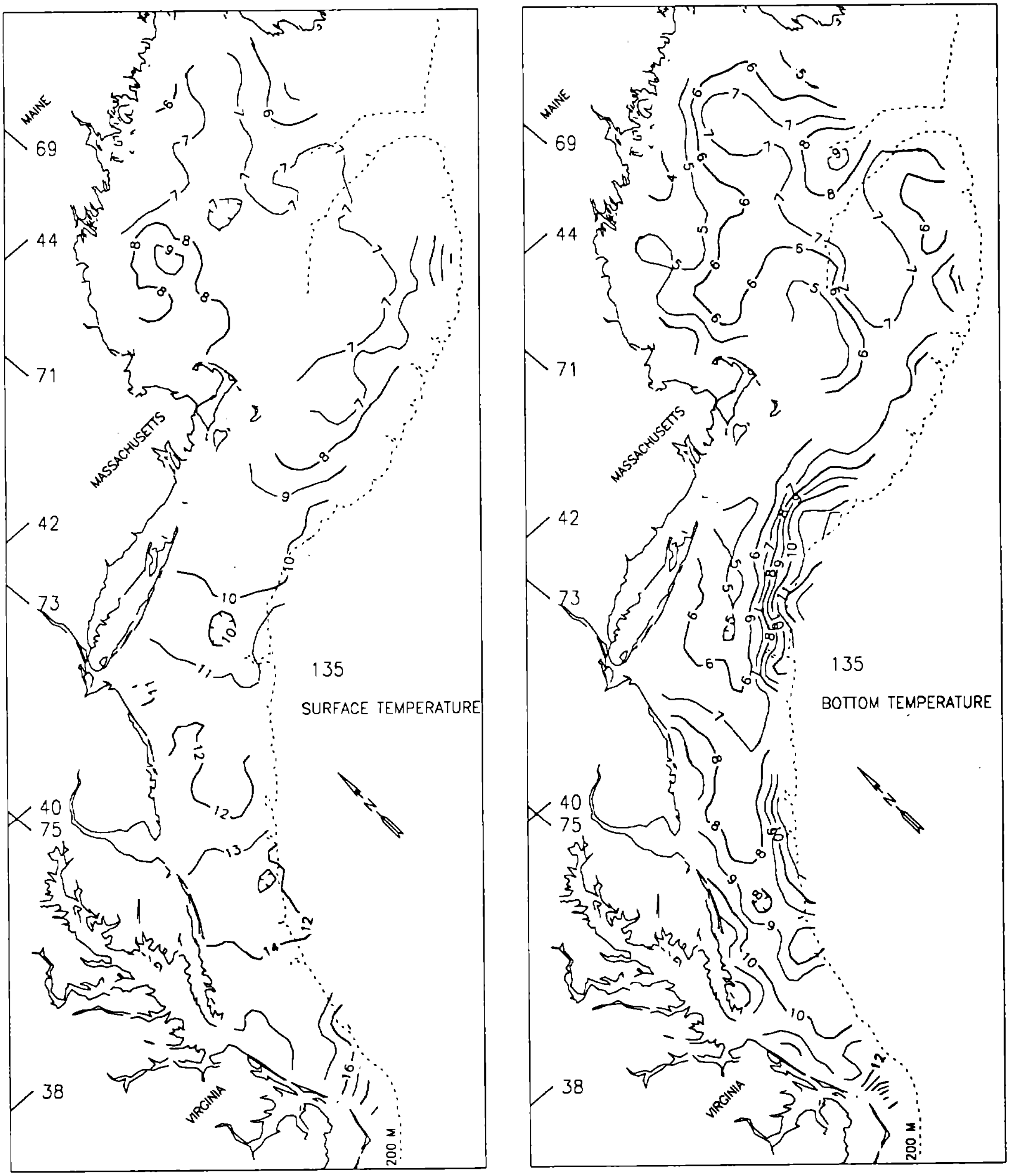


Figure 12. Expected (a) surface and (b) bottom temperature (ºC) for May 15. The large numbers above the legend indicate the Julian day.

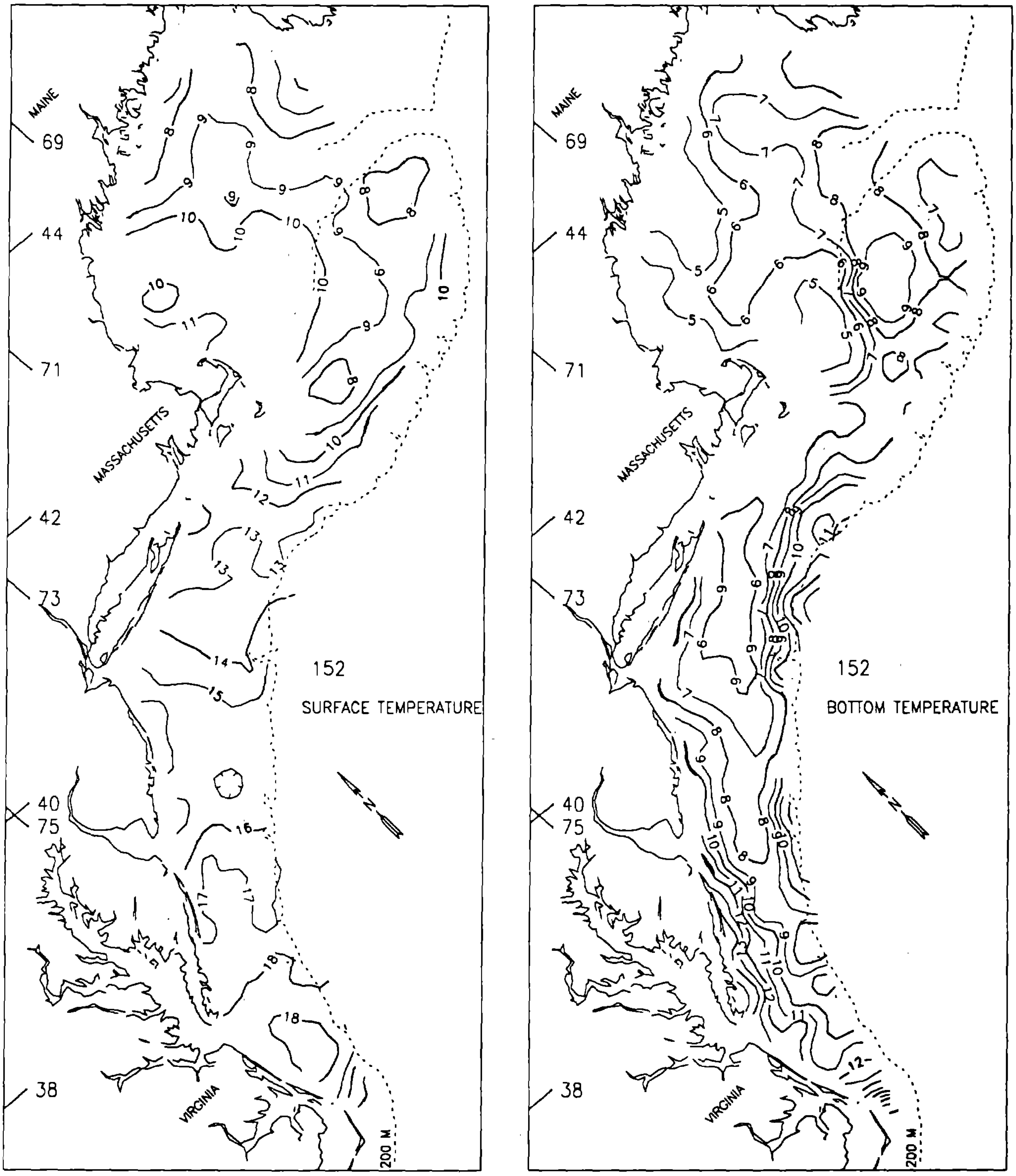


Figure 13. Expected (a) surface and (b) bottom temperature (ºC) for June 1. The large numbers above the legend indicate the Julian day.

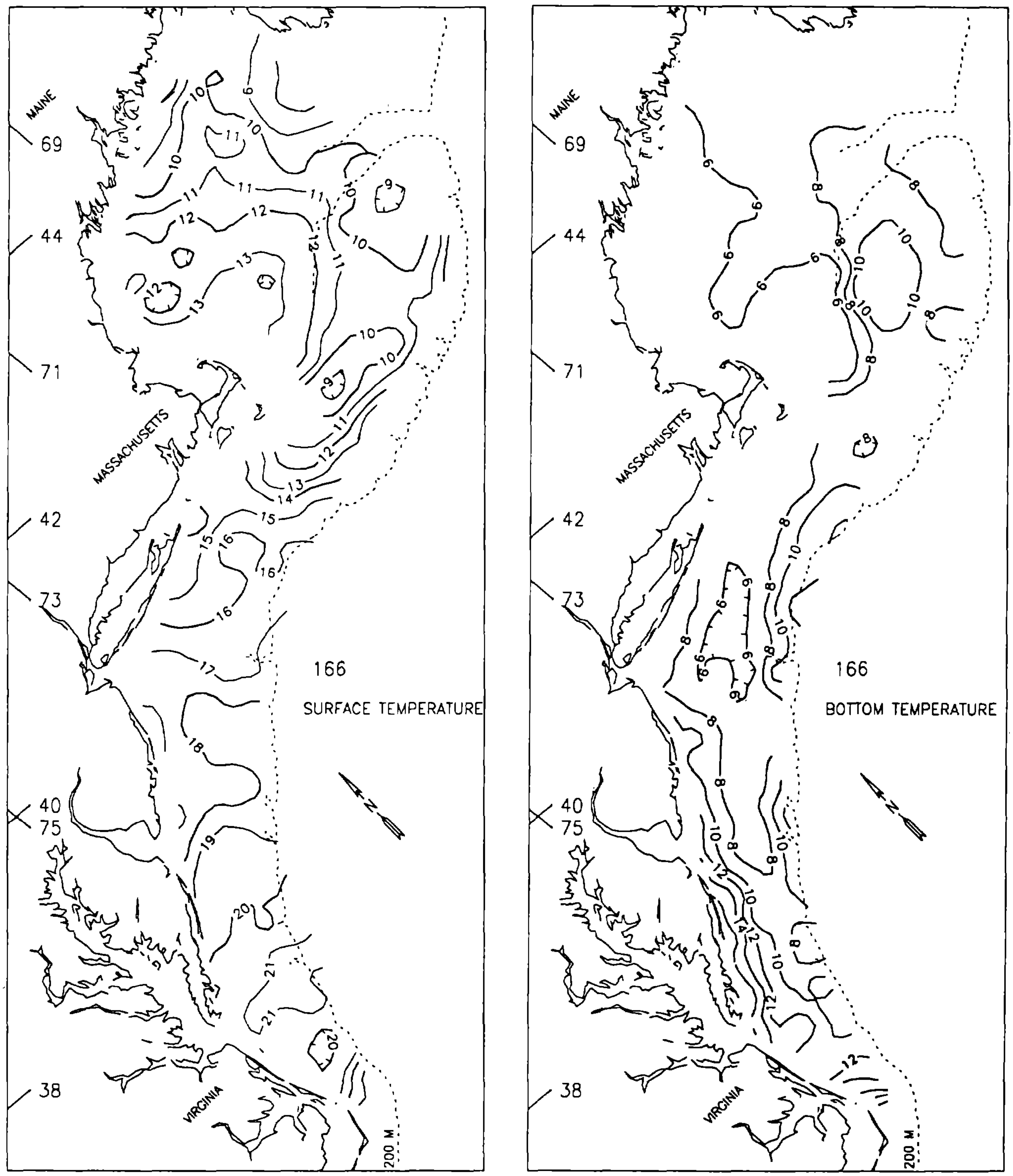


Figure 14. Expected (a) surface and (b) bottom temperature (“C) for June 15. The large numbers above the legend indicate the Julian day.

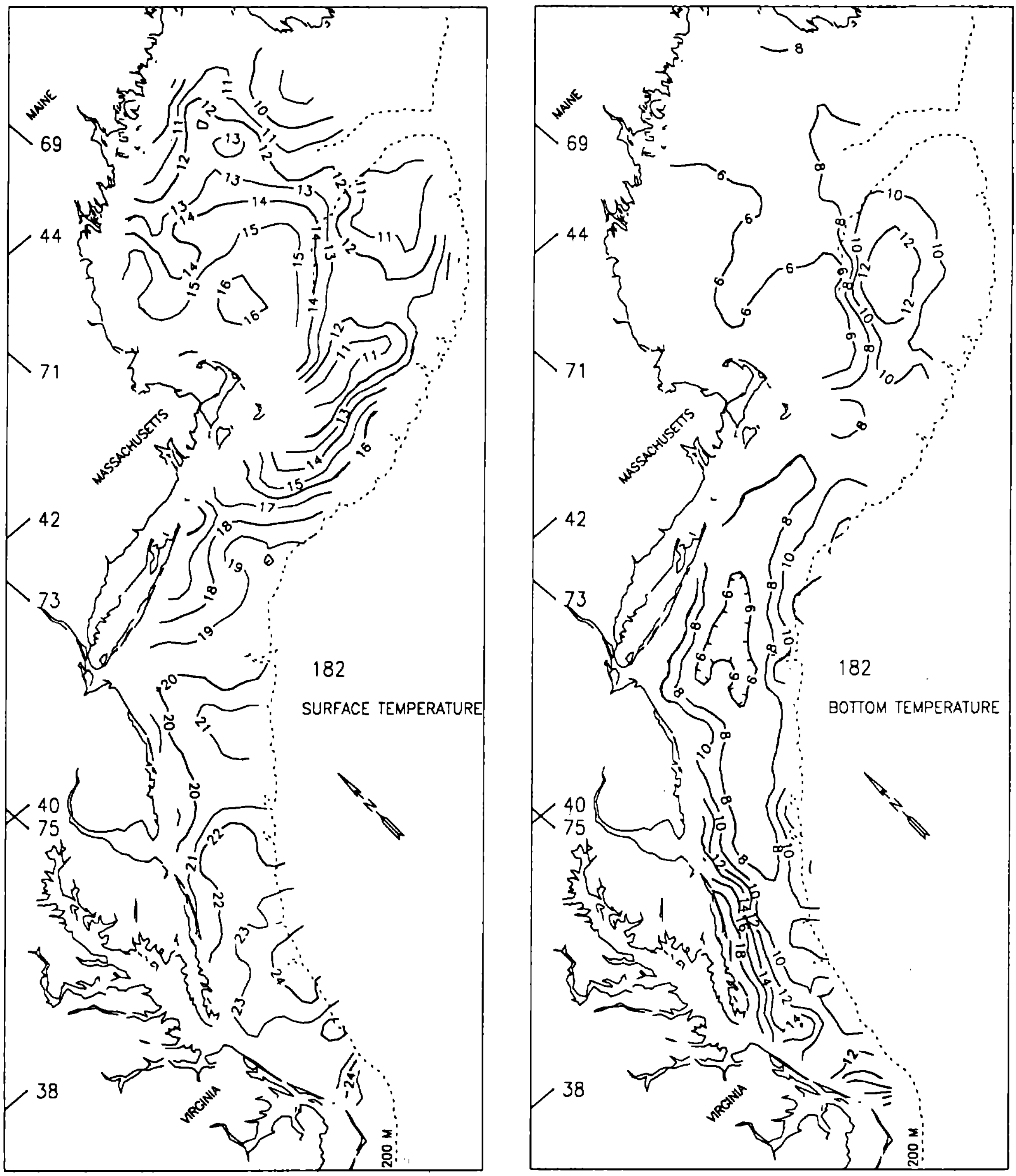


Figure 15. Expected (a) surface and (b) bottom temperature (‘C) for July 1. The large numbers above the legend indicate the Julian day.

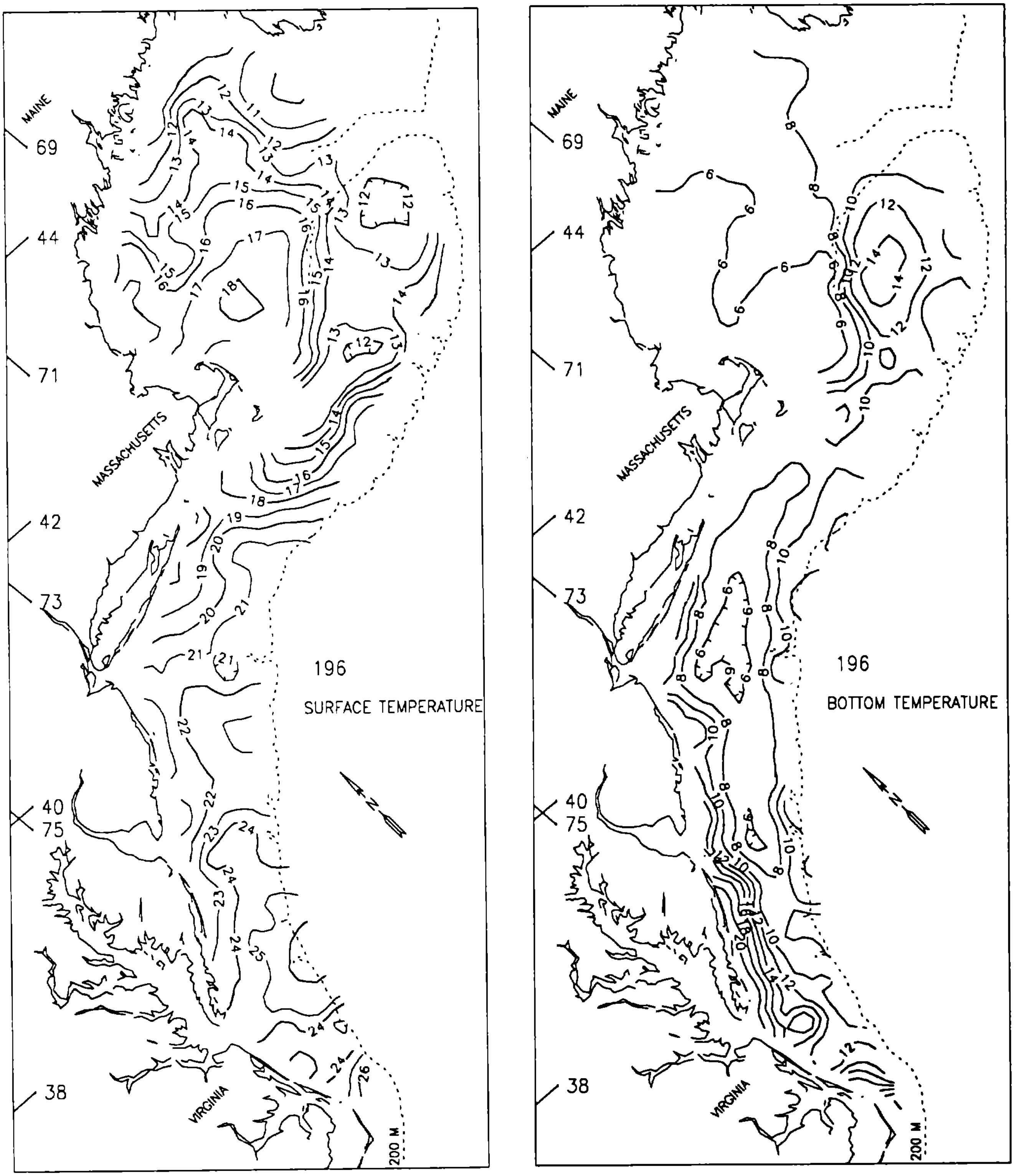


Figure 16. Expected (a) surface and (b) bottom temperature (“C) for July 15. The large numbers above the legend indicate the Julian day.

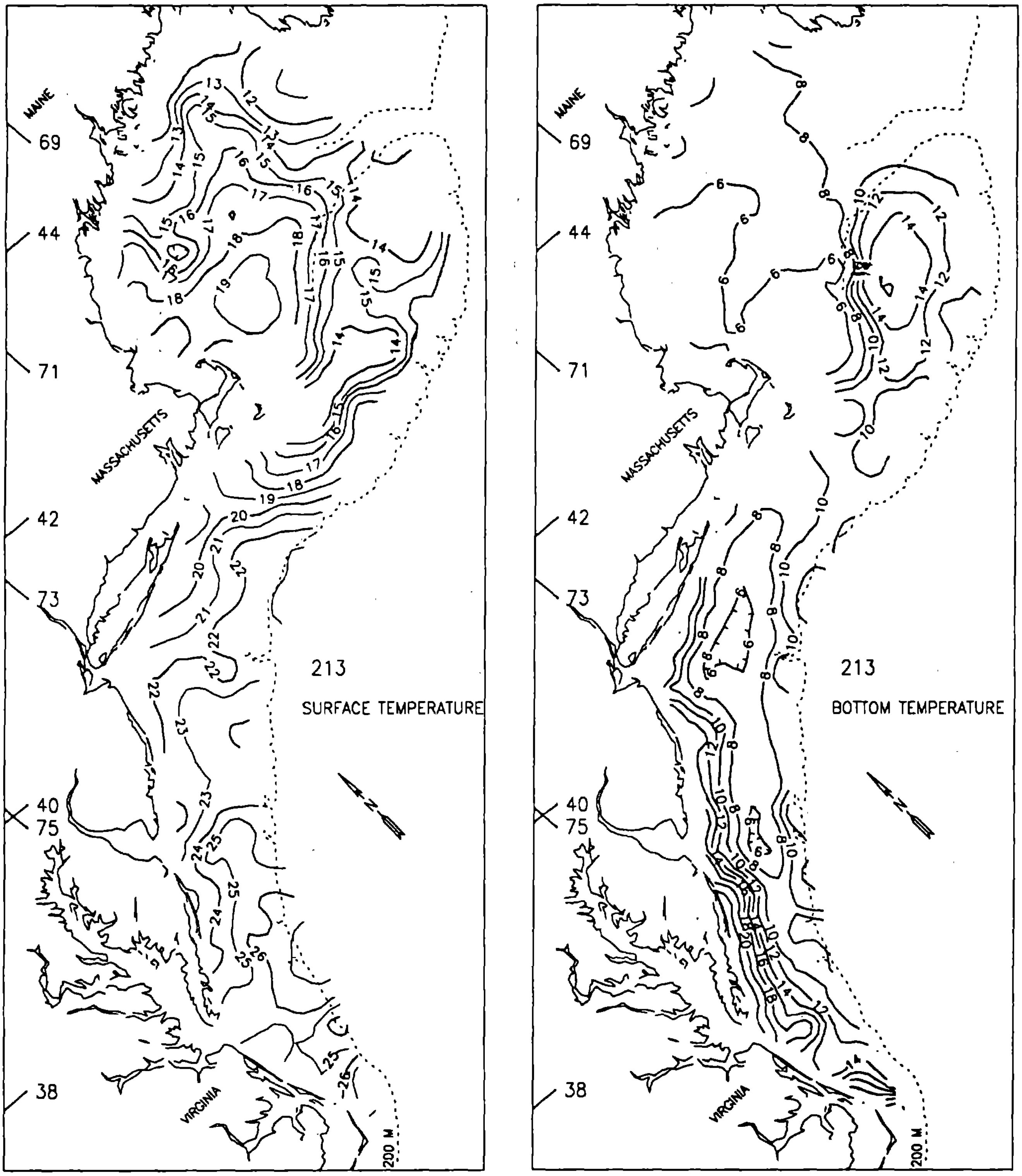


Figure 17. Expected (a) surface and (b) bottom temperature (“C) for August 1. The large numbers above the legend indicate the Julian day.

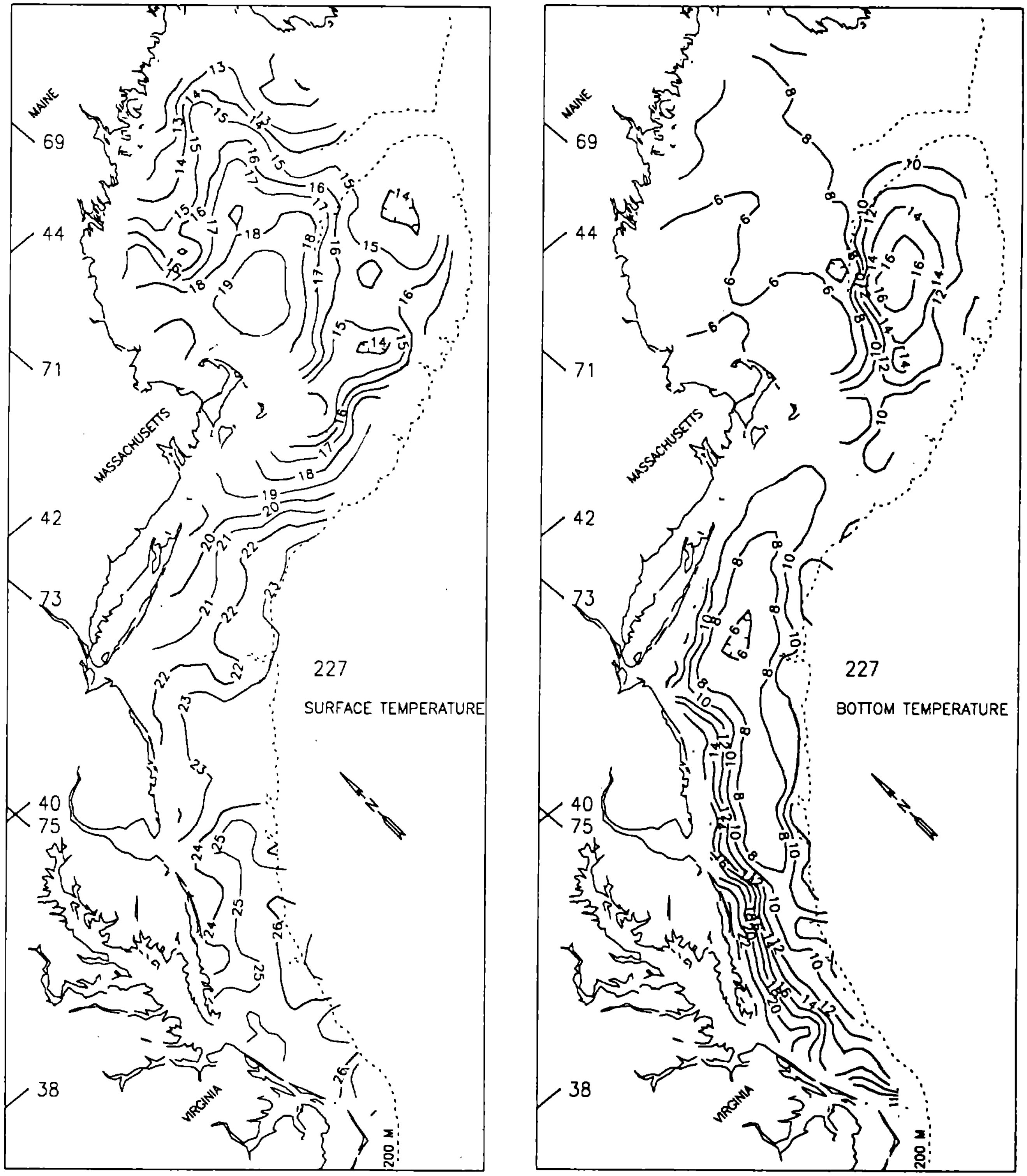


Figure 18. Expected (a) surface and (b) bottom temperature (‘C) for August 15. The large numbers above the legend indicate the Julian day.

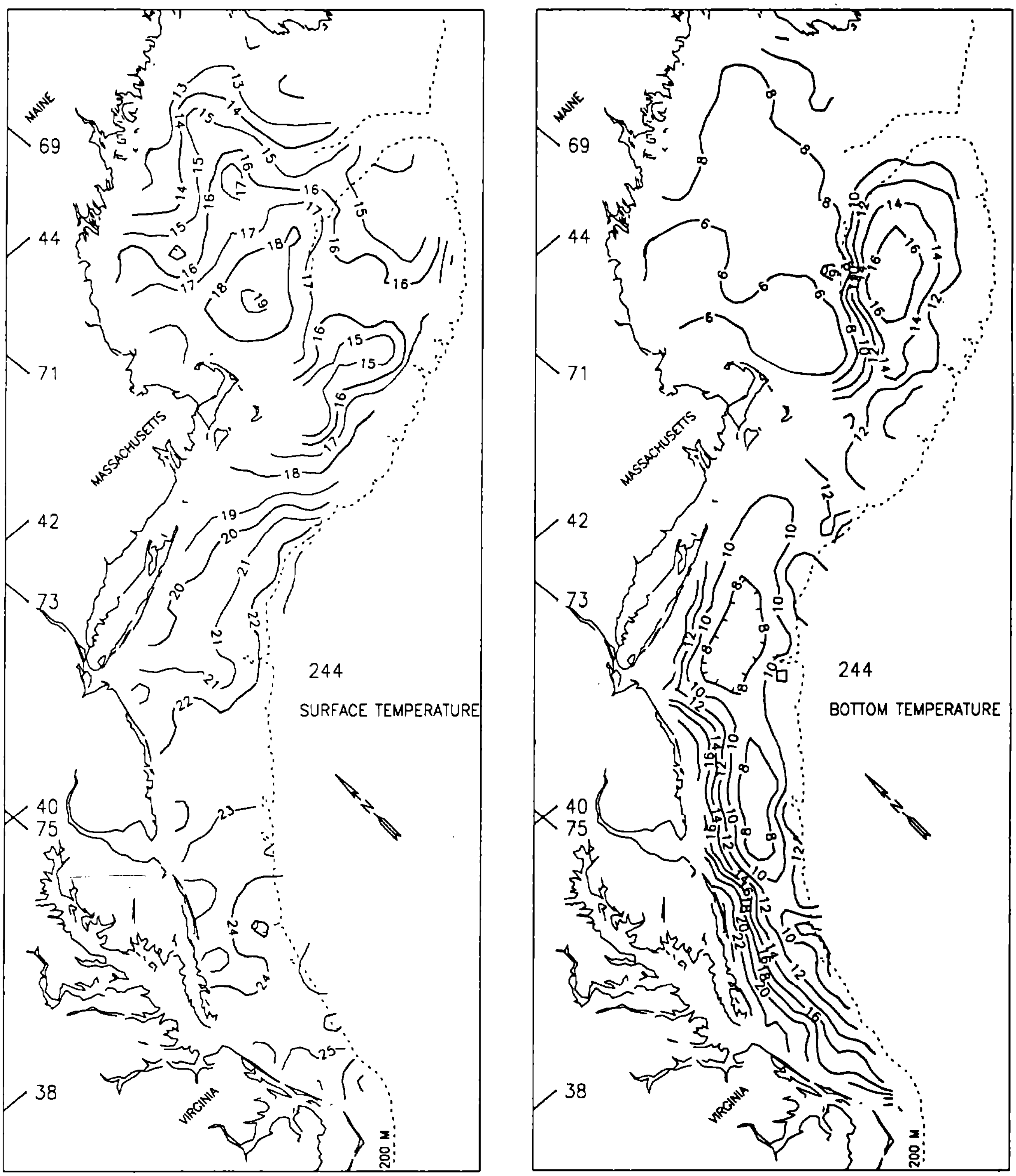


Figure 19. Expected (a) surface and (b) bottom temperature (‘C) for September 1. The large numbers above the legend indicate the Julian day.

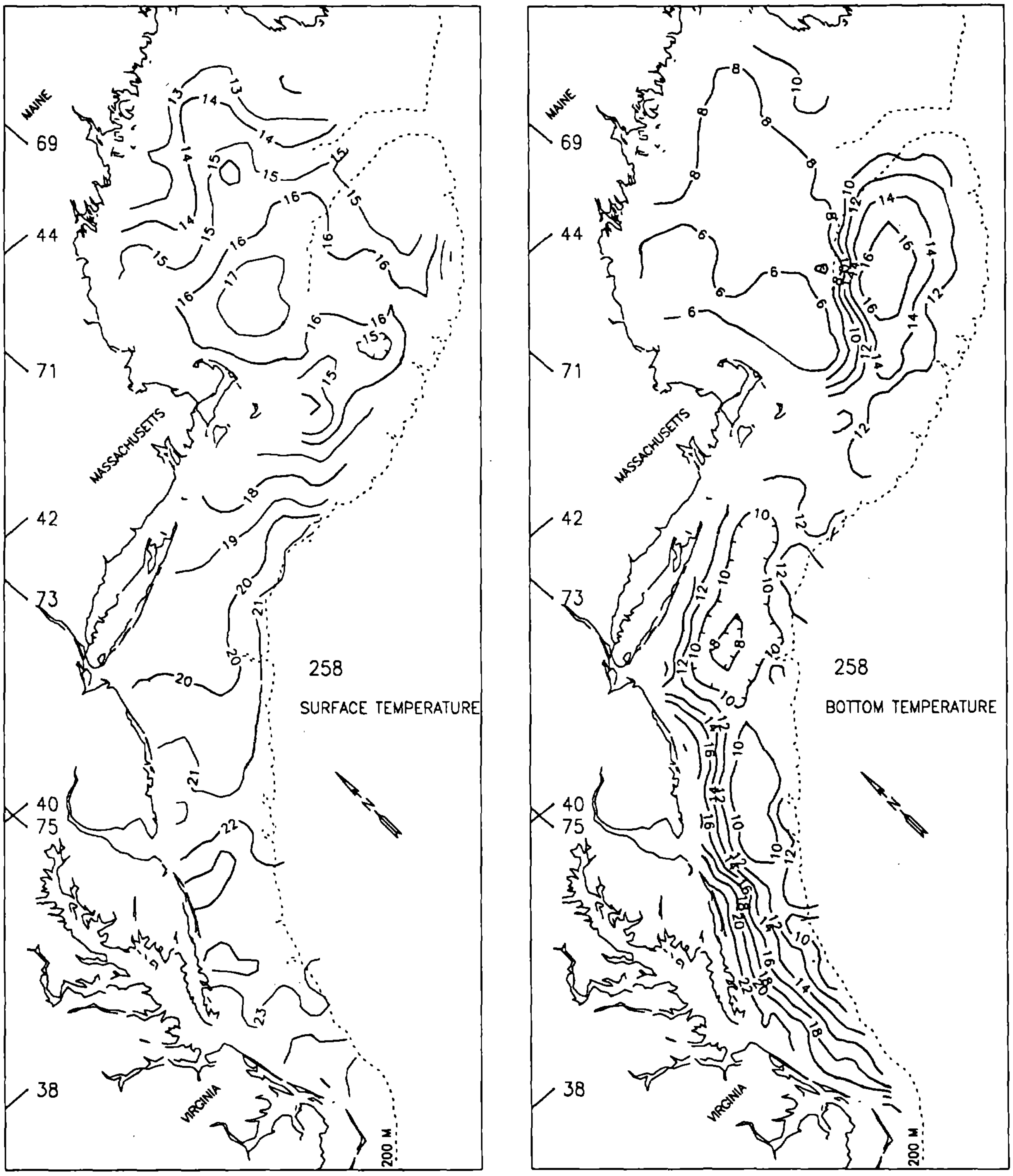


Figure 20. Expected (a) surface and (b) bottom temperature (‘C) for September 15. The large numbers above the legend indicate the Julian day.

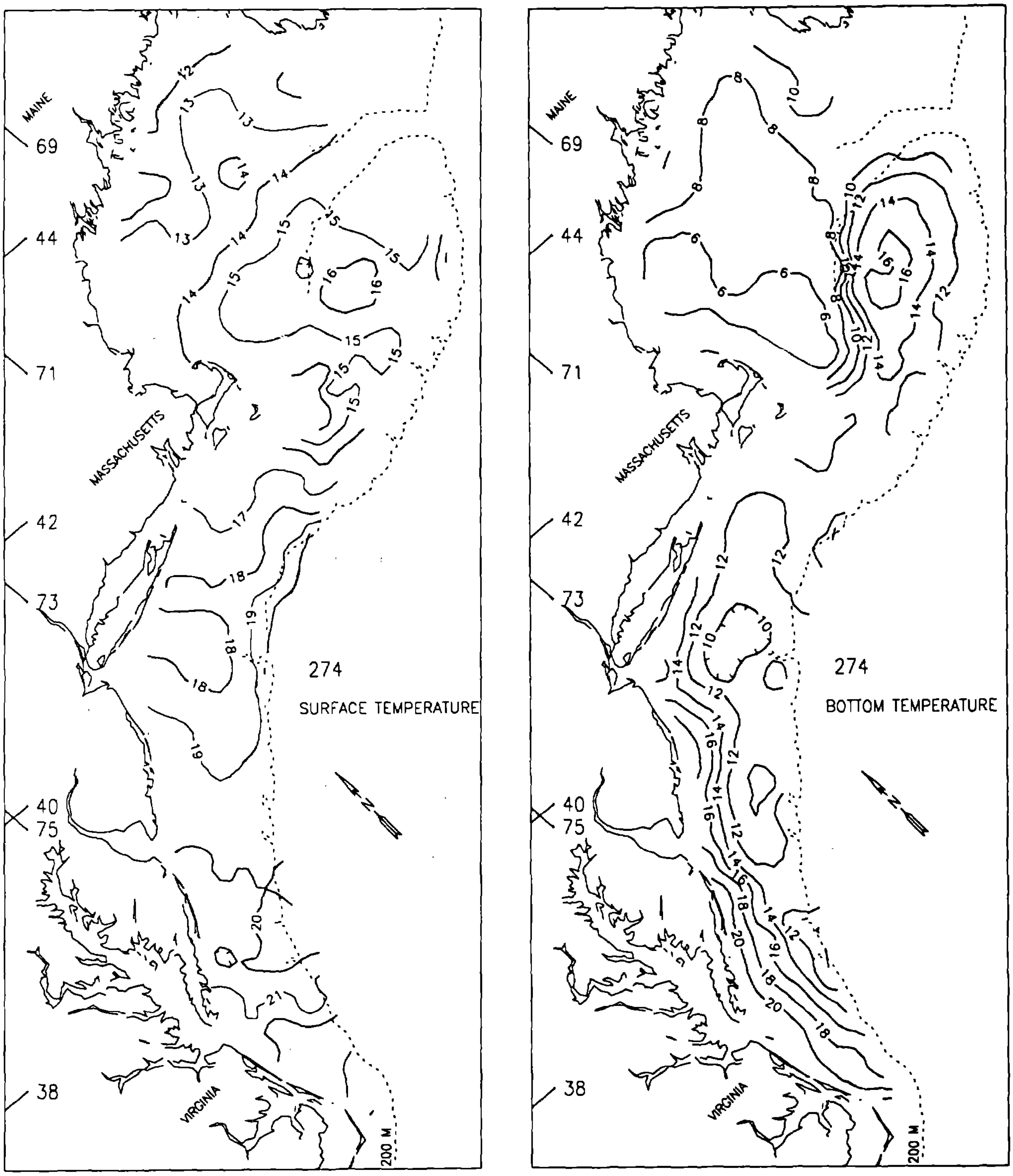


Figure 21. Expected (a) surface and (b) bottom temperature (ºC) for October 1. The large numbers above the legend indicate the Julian day.

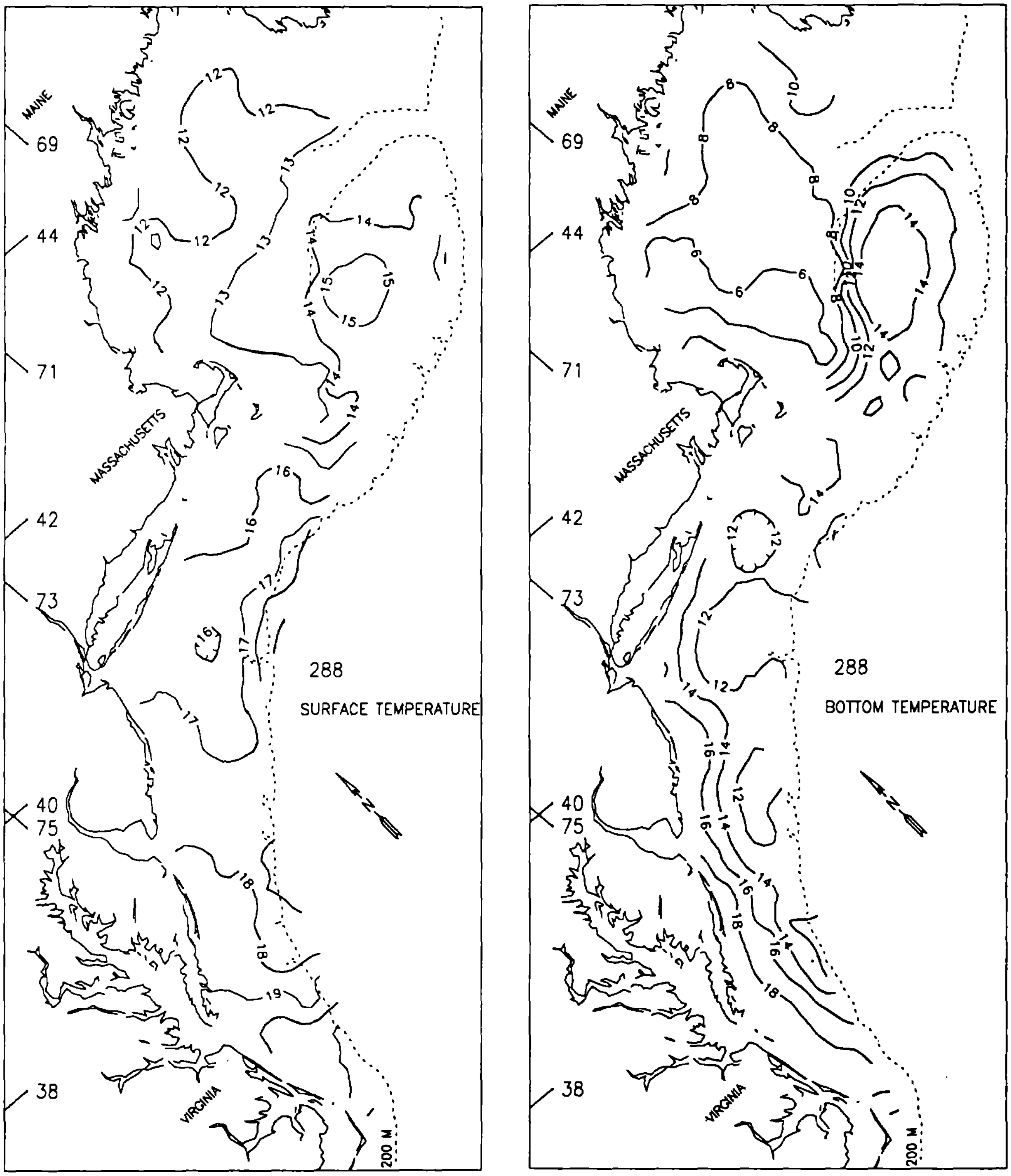
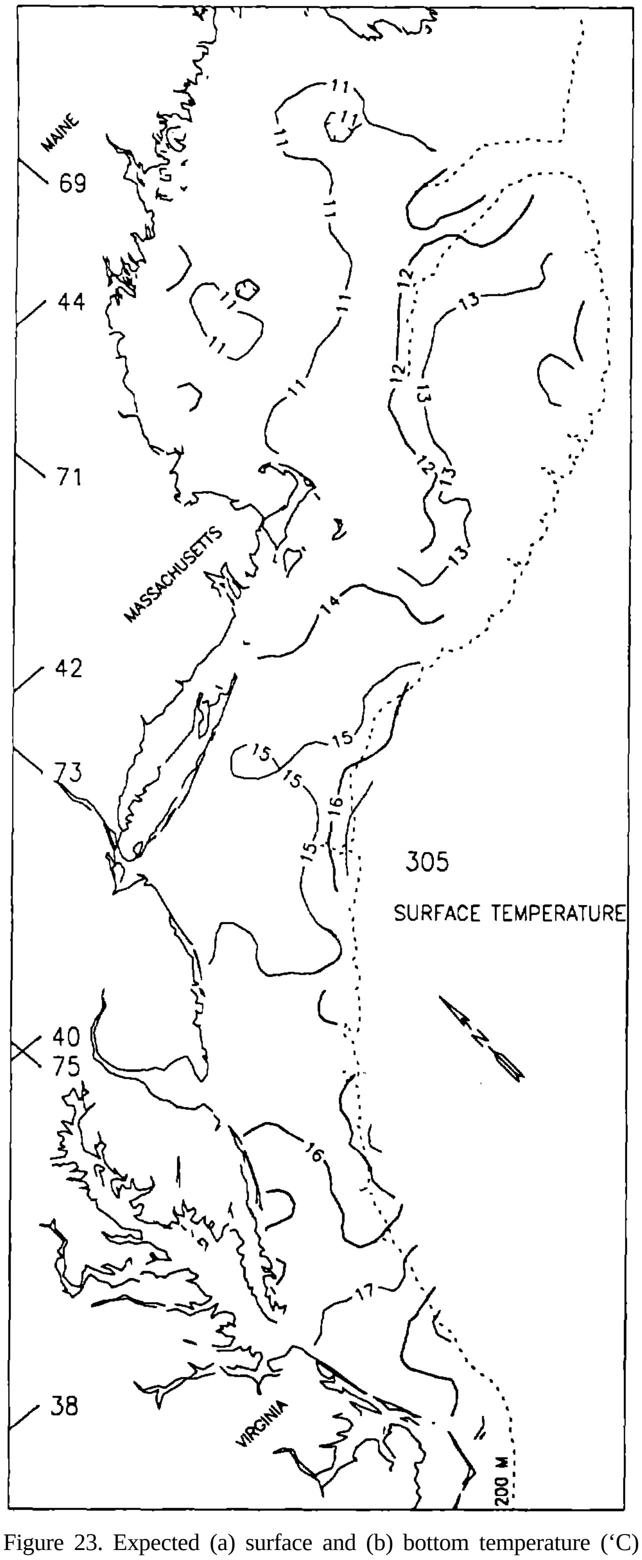


Figure 22. Expected (a) surface and (b) bottom temperature (ºC) for October 15. The large numbers above the legend indicate the Julian day.



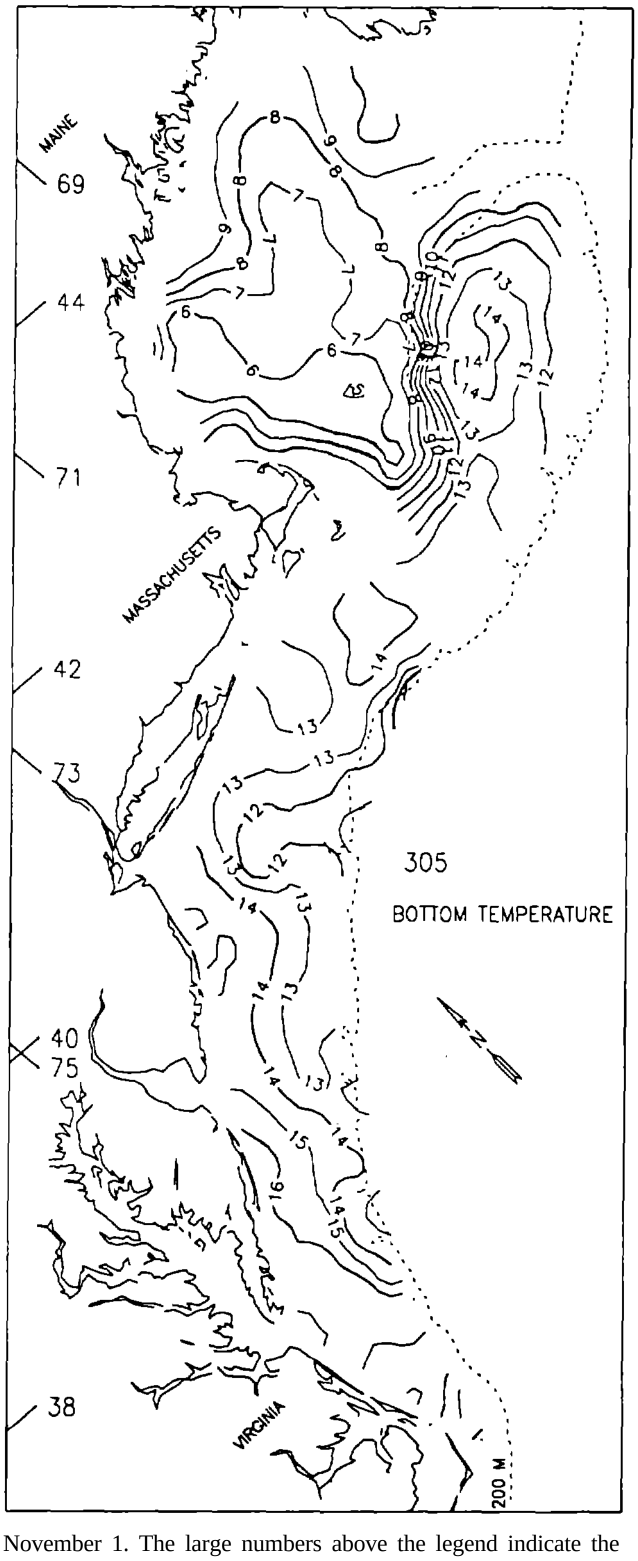


Figure 23. Expected (a) surface and (b) bottom temperature (‘C) for November 1. The large numbers above the legend indicate the Julian day.

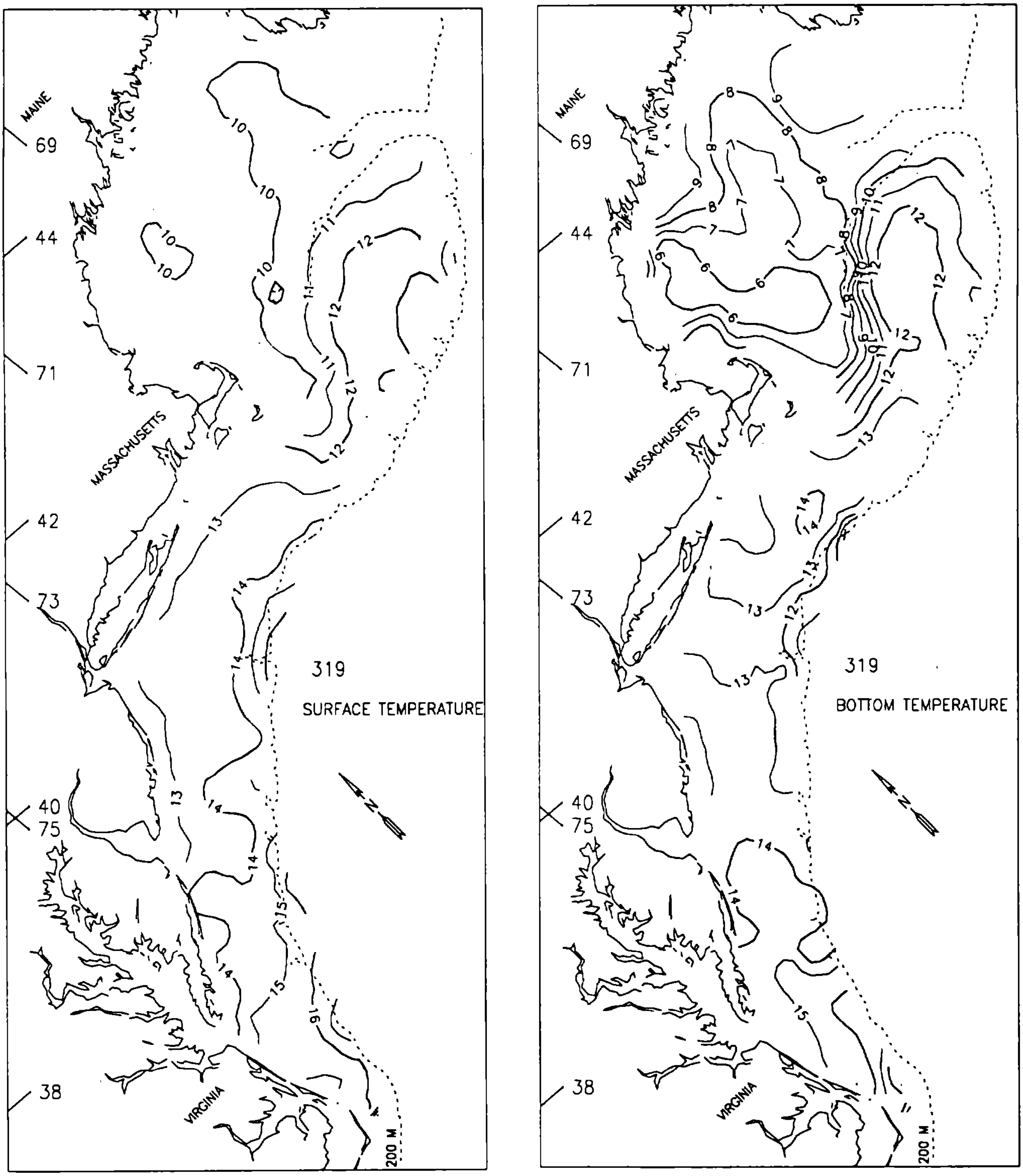


Figure 24. Expected (a) surface and (b) bottom temperature (‘C) for November 15. The large numbers above the legend indicate the Julian day.

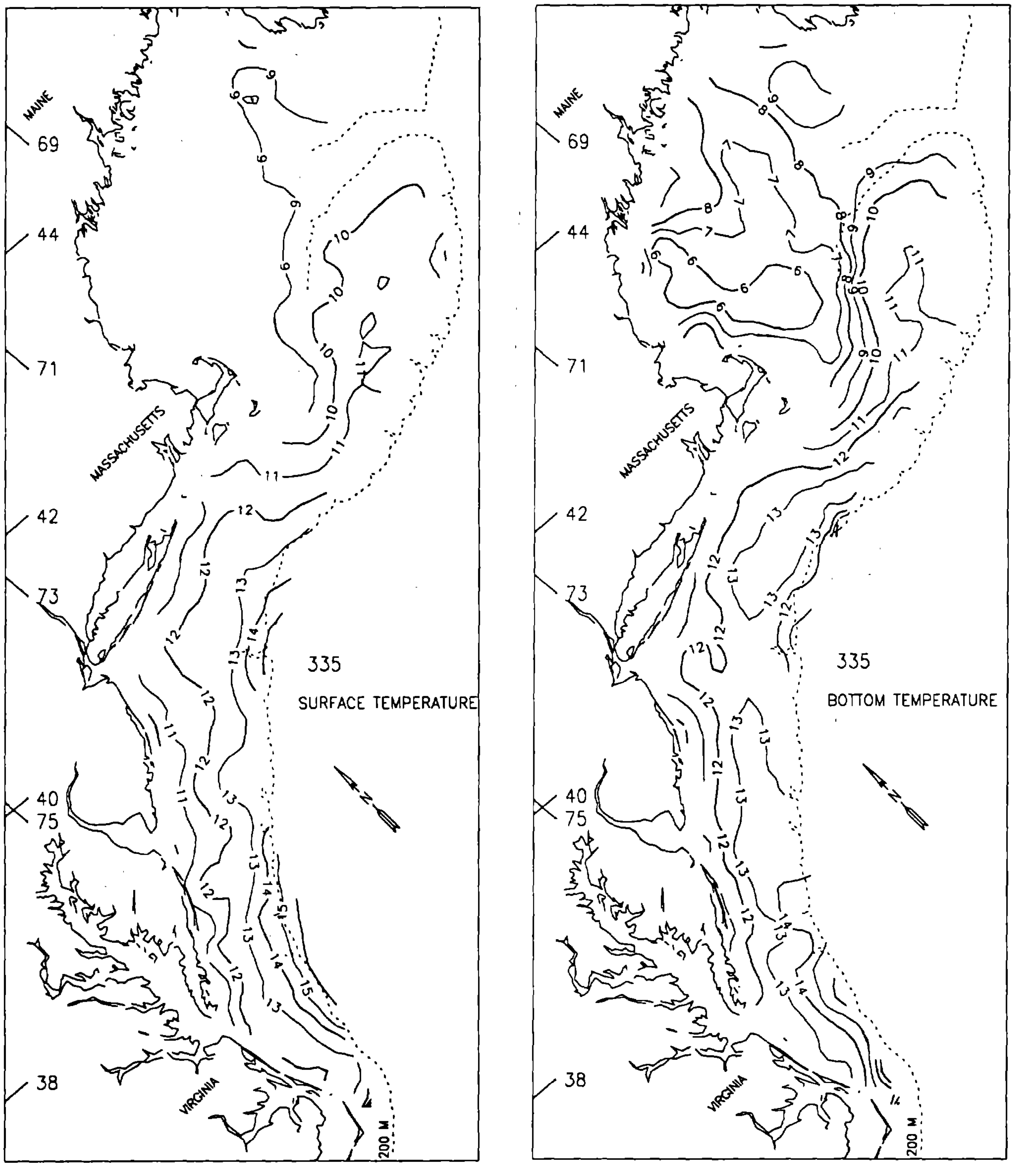


Figure 25. Expected (a) surface and (b) bottom temperature ("C) for December 1. The large numbers above the legend indicate the Julian day.

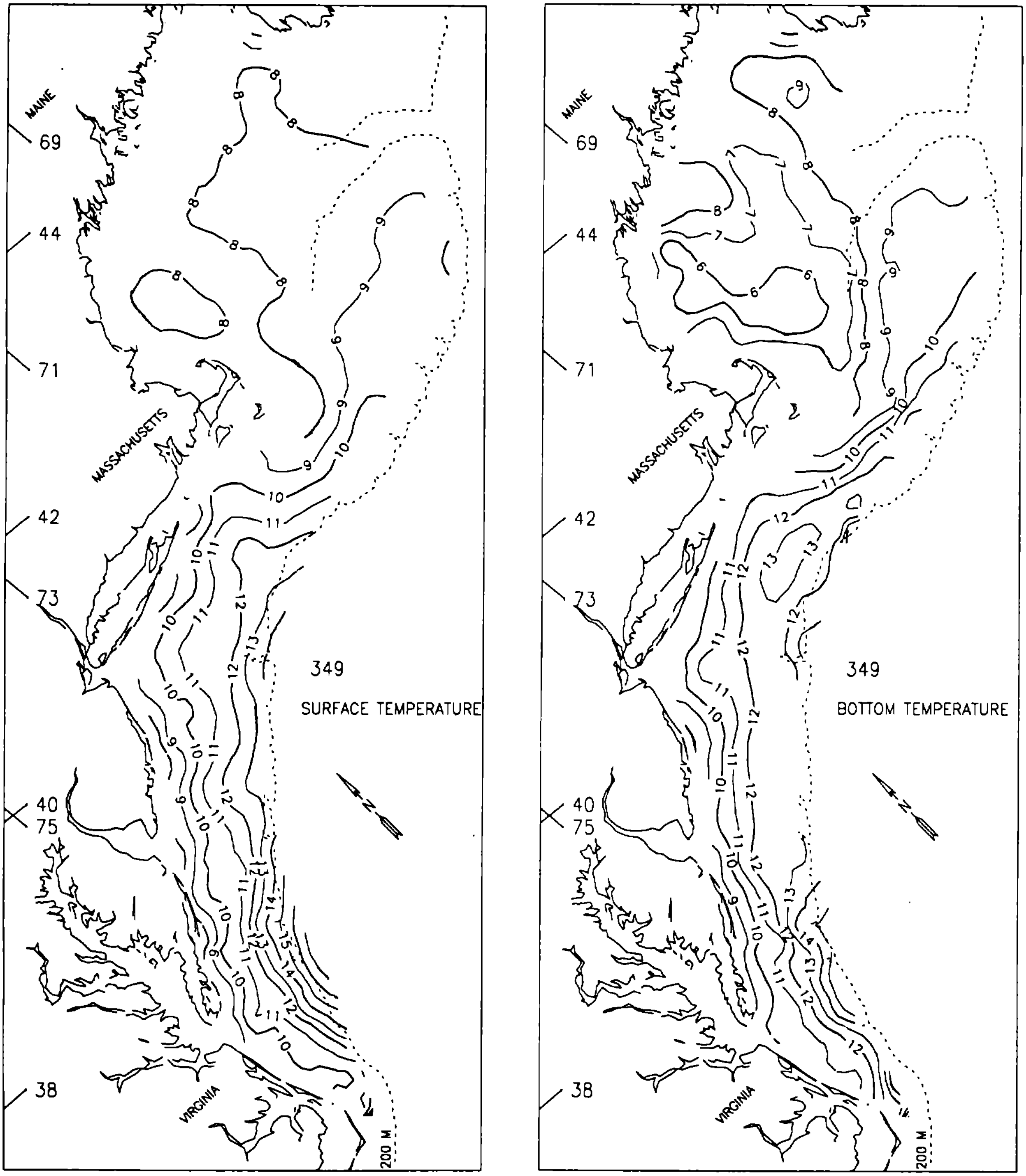


Figure 26. Expected (a) surface and (b) bottom temperature (“C) for December 15. The large numbers above the legend indicate the Julian day.

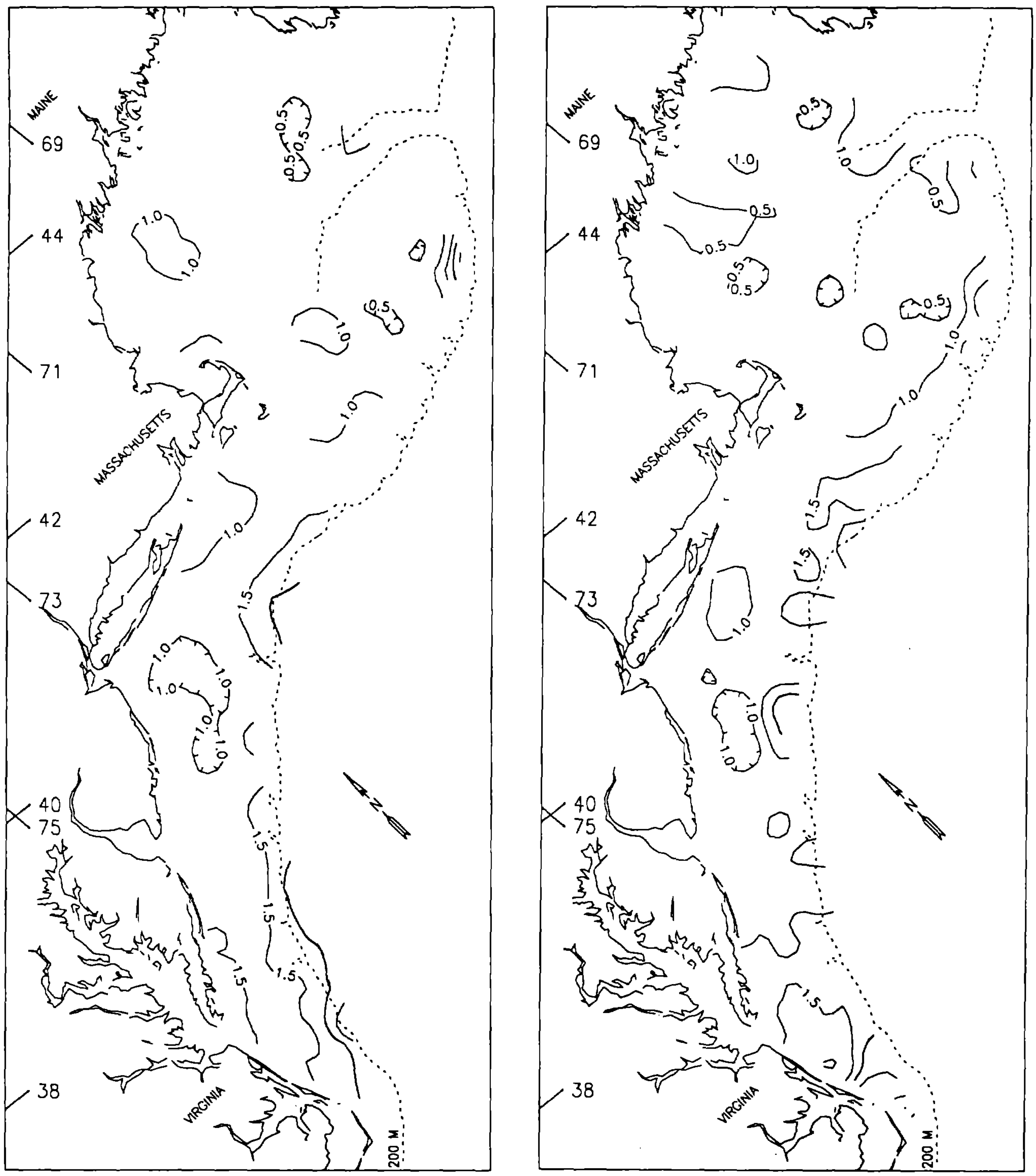


Figure 27. Standard deviation of the original data from the calculated annual temperature curves for (a) the surface and (b) the bottom.

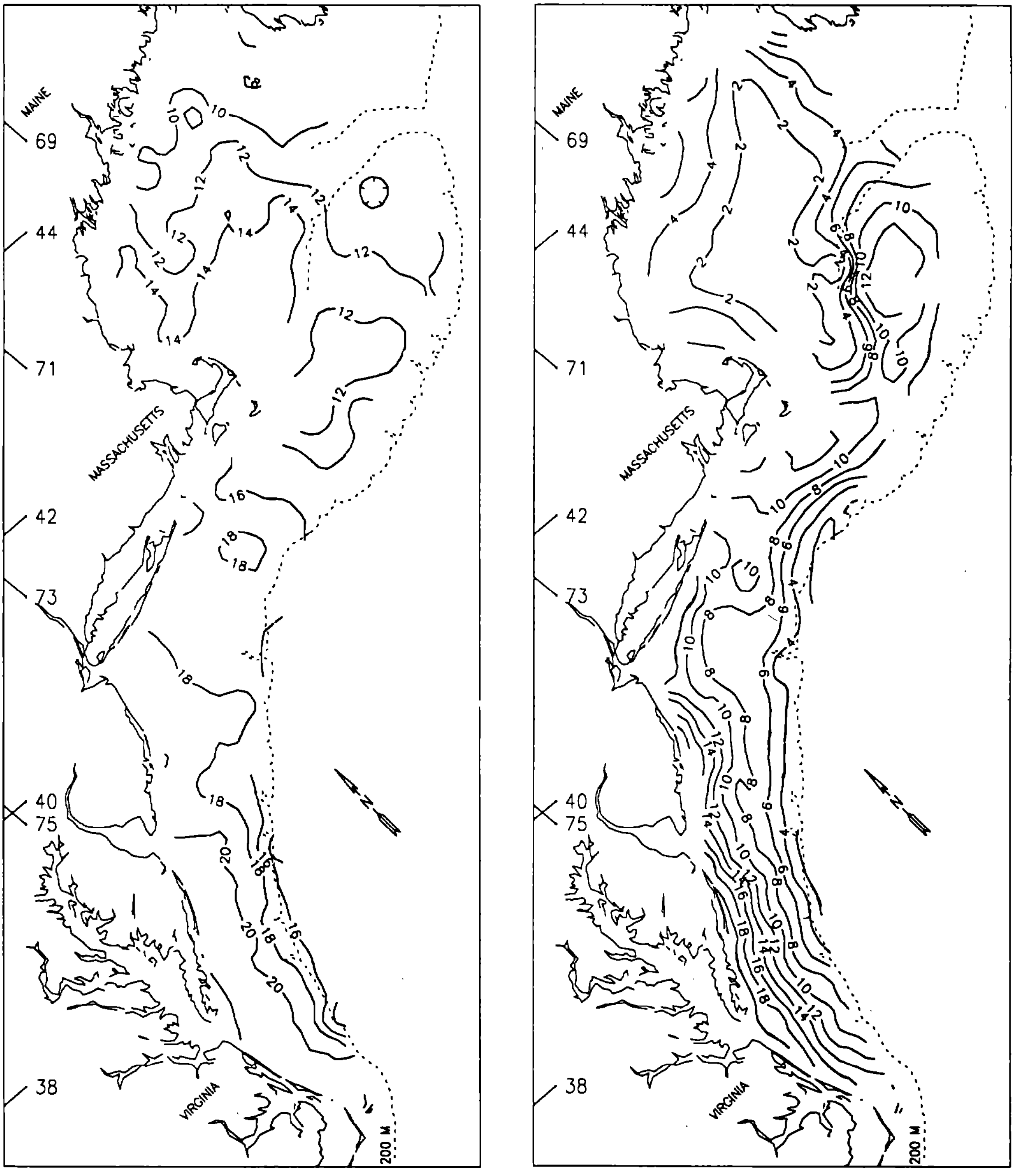


Figure 28. Annual range in expected temperature for (a) the surface and (b) the bottom.

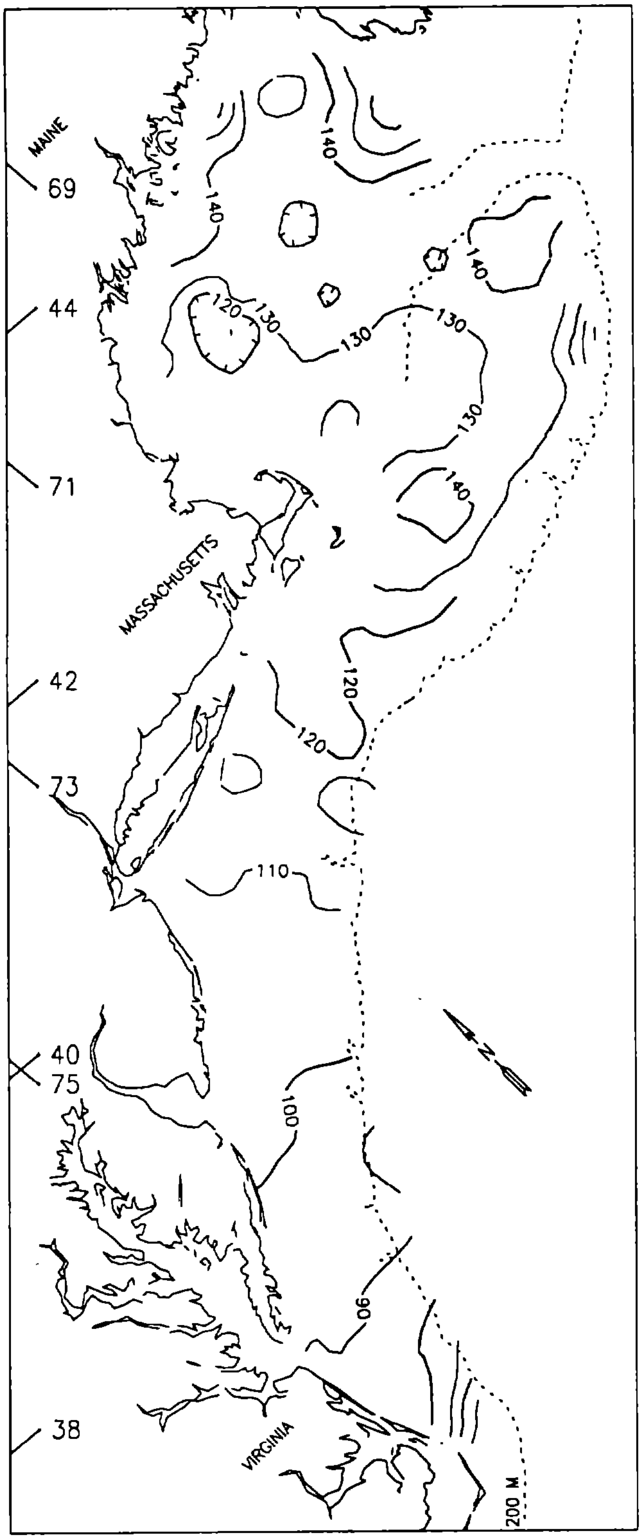


Figure 29. The day of the year (Julian day) that the expected surface temperature first rises above 7ºC during the warming cycle.

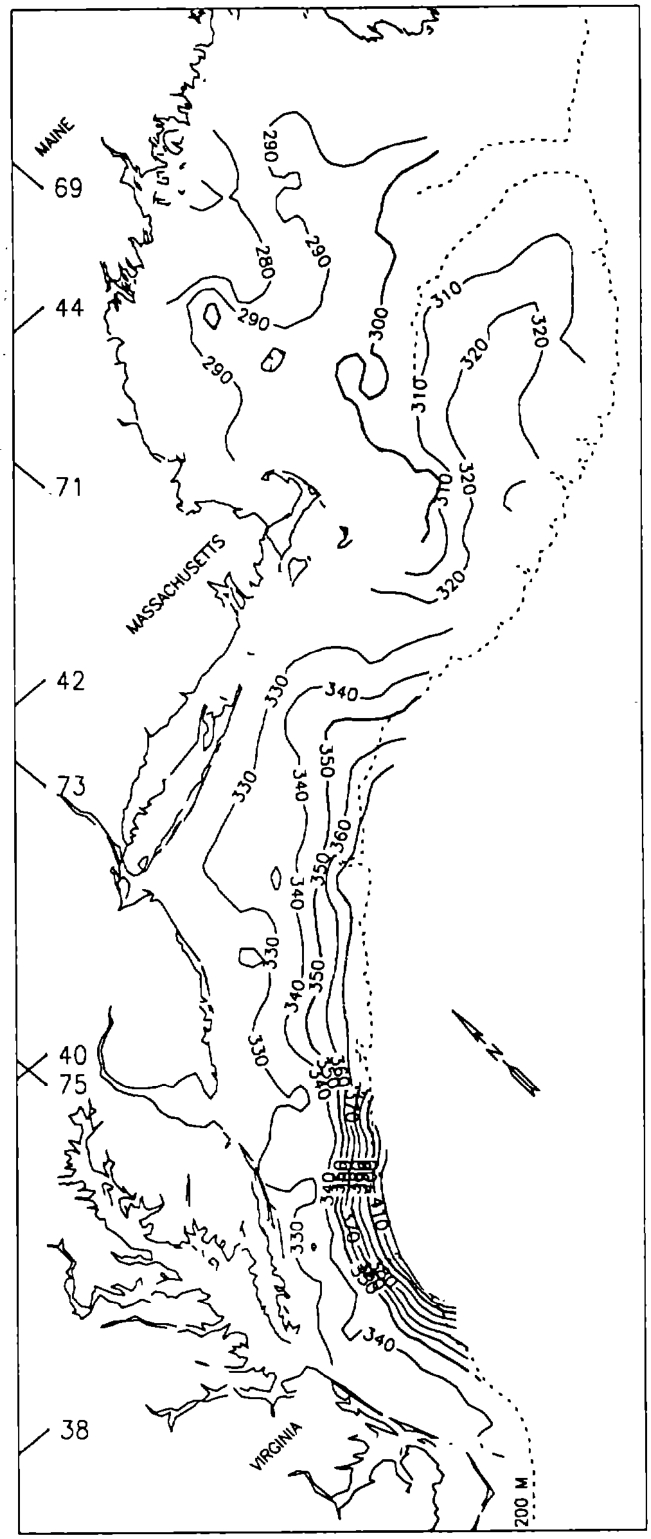


Figure 30. The day of the year (Julian day) that the expected surface temperature first falls below 12ºC in the cooling cycle. To allow a smooth progression from December into January, days in the beginning of the year are represented by their Julian day t 365.

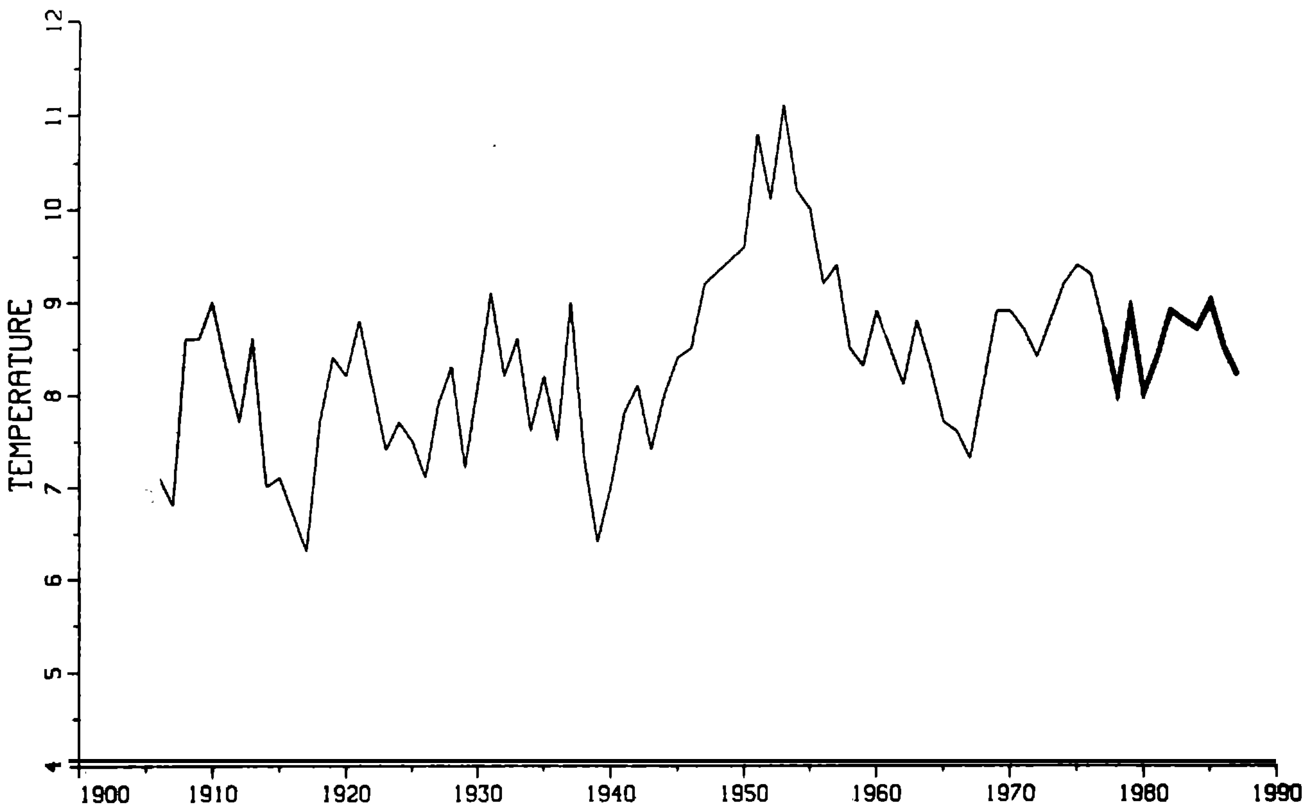


Figure 31. Average annual surface temperature at Boothbay Harbor, Maine, as reported by Churchill (1988). The ll-year period (1977-87) during which the data used in this report were obtained is highlighted by a heavier line.

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(continued from inside front cover)

58. An Indexed Bibliography of Northeast Fisheries Center Publications and Reports for 1987. By Jon A. Gibson. August 1988. iii + 20 p. NTIS Access. No. PB89-113013/AS.

59. Surveys of Breeding Penguins and Other Seabirds in the South Shetland Islands, Antarctica, January-February 1987. By W. David Shuford and Larry B. Spear. September 1988. vii + 27 p., 14 figs., 1 table. NTIS Access. No. PB89-141311/AS.

60. Survey of Antarctic Fur Seals in the South Shetland Islands, Antarctica, during the 1986-1987 Austral Summer. By John L. Bengtson, Lisa M. Ferm, Tero J. Harkonen, Everett G. Schaner, and Brent S. Stewart. September 1988. vii + 8 p., 1 fig., 3 tables. NTIS Access. No. PB89-141303/AS.

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63. Status of the Fishery Resources Off the Northeast&n United States for 1988. By Conservation and Utilization Division. October 1988. iii + 135 p., 51 figs., 52 tables. NTIS Access. No. PB89-130819/AS.

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67. Response of the Habitat and Biota of the Inner New York Bight to Abatement of Sewage Sludge Dumping. Second Annual Progress Report -- 1988. By Environmental Processes Division, Northeast Fisheries Center. July 1989. vii + 47 p., 39 figs., 11 tables, 3 app. NTIS Access. No. PB90-160656/AS.

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69. The 1988 Experimental Whiting Fishery: A NMFS/Industry Cooperative Program. By Frank P. Almeida, Thurston S. Bums, and Sukwoo Chang. August 1989. v t 16 p., 9 figs., 11 tables, 1 app. NTIS Access. No. PB90-160664/AS.

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